

CONTINUOUS EMISSION MONITORS

Compliance Assistance Program
California Environmental Protection Agency
Air Resources Board

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100 INTRODUCTION

Continuous Emission Monitoring

The Compliance Assistance Program (CAP) is an effort by the California Air Resources Board to provide assistance to local air pollution control districts in conducting more comprehensive, consistent, and accurate compliance inspections; and to provide industry with information and tools to attain and remain in compliance with federal, state, and district rules and regulations. By assisting industry and local districts in compliance determinations, CAP intends to reduce emissions to the air and improve industry compliance rates.

Compliance Assistance Program

The CAP produces user-friendly documents targeted to identified needs of specific audiences. These documents include technical manuals (as this document is), handbooks (often referred to as "comic books" due to their informal style), and quick reference pamphlets.

This manual is intended as a dynamic document to assist with the highly technical and rapidly changing field of continuous emission monitoring. As the state of the technology advances, and as the regulatory environment changes, this manual will be periodically updated. Additionally, updates to this manual rely on the user to identify important issues. As you read the manual, please send your comments and proposed revisions and amendments to:

Manual Updates

Air Resources Board
Compliance Division, Compliance Assistance Section
P.O. Box 2815
Sacramento, CA 95812

When you first receive this manual, or if the manual changes hands, please be sure to fill out the tracking card located in the front of the manual and **promptly mail it to the ARB**. The tracking cards also are used to keep us up to date of any address changes. Revisions of the manual are distributed to the registered holder of the manual, based on our records from the tracking cards.

Registration

The organization of this manual is divided into chapters relevant to the basic information and regulations about continuous emission monitors (CEM) (Section 100), a detailed overview of the important aspects of CEMs (Section 200), basic requirements of installation and operation (Section 300), equipment certifications and testing (Section 400), and data reports required by air pollution agencies (Section 500). A glossary contains important terms and a table of units and conversion factors. Finally, the appendices contain important additional information, including the text of pertinent regulations (current as of this writing) and a series of forms that can be copied and/or modified for test and data reporting.

Manual Organization

100 INTRODUCTION

101 INTRODUCTION TO CONTINUOUS EMISSION MONITORS

Concern over air quality has resulted in a myriad of air pollution rules, regulations, and permits in recent years. Often the emission control equipment, or procedures to limit the emission of pollutants into the air, are written into the regulations or source specific permits. After these pollutant reduction requirements are established, how does an air pollution control agency know whether the equipment and procedures are operating and doing the job expected? The answer is to use continuous emission monitoring systems.

To select the proper analyzer and monitoring system, considerable information should be at hand about the unit and facility to be monitored, regulation requirements, and the equipment available to be used. In addition to knowing these things, it is critical to aggregate them into an integrated monitoring program. Unless the system, including the monitoring system and facility equipment, computer software, quality assurance and quality control procedures, human resources, and legal requirements functions as a cohesive whole, the system will not fulfill its expectations and potential.

CEM Systems

Continuous emission monitoring systems constitute a unified set of equipment and activities to determine and report emission levels of air pollutants. The instruments and procedures have been (and continue to be) shaped primarily by regulatory requirements. These regulations sometimes have been technology forcing in that, at the time the regulation was written, cutting edge instrumentation with only experimental field applications were in existence. This situation is expected to continue. Continuing feedback between regulatory requirements and the state of emission monitoring technology should continue to drive the field. As new regulations and technologies are developed, this manual will be updated.

Science and Regulation

Therefore, this manual will examine the interplay of science and regulation in the use, design, and certification of CEM systems and will illustrate the current and projected regulatory scenario. Specific regulatory and reporting requirements should be obtained from the relevant air pollution control agency and updated as the technology and requirements change.

100 INTRODUCTION

Continuous Emission Monitoring

102 USES OF CEM SYSTEMS

Although CEM systems are largely driven by regulatory requirements, there are important uses of CEM data for both the regulatory agency and the regulated industry. The most obvious use of CEM data is for the detection and reporting of excess emissions. One of the earliest intentions of CEM requirements was that the emission data should track the control system's performance¹. New fossil-fuel-fired steam generators, petroleum refineries, nitric acid plants, and sulfuric acid plants were the first source categories required, in 1975, to report their excess emissions on a quarterly basis. Excess emissions reports can be used to:

- Provide a continuous record of the source's ability to comply with emissions standards.
- Provide the control agency with data concerning frequency, times, quantities of emissions, etc. of upset conditions.
- Provide data to pursue enforcement actions.
- Screen sources in inspection targeting programs.
- Provide data concerning trends in control equipment operation and performance.
- Indicate whether the source is using good operation and maintenance practices.

In providing data for enforcement actions, unless the regulation requiring the CEM specifically states that the CEM data is to be used for compliance determination, the data can only be used as an indicator that a problem exists. Legally enforceable data would then need to be collected through other action, such as performance and reference method tests. In regulations where the CEM system data are to be used for direct compliance determinations, the data can be used to establish whether or not the source is in violation of an emission standard and legal enforcement action initiated or fines levied². Documenting a violation using a direct compliance CEM is often much like a speeding ticket; if the source is over the limit, a fine can be levied.

The California Air Resources Board considers all CEM systems to be direct compliance instruments and requires the air pollution control districts in California (which implement stationary source regulations at the local level) to utilize

Agency Uses of CEMs

Direct Com- pliance vs Compliance Indicating

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CAM

CEM systems in their enforcement programs. Increasingly, the federal CEM programs also use the CEM systems for direct compliance determinations. The new Compliance Assurance Monitoring (CAM)^{3,4,5} program is be designed to further these goals.

Facility Uses of CEMs

The CEM data are also useful in providing public assurances that emissions (especially of toxic pollutants) are within allowable levels. This can be an advantage to the facility since it can alleviate public concerns about the emissions and make the source operators appear to be better public citizens.

Emissions Trading Programs

An increasingly popular technique to reduce ambient concentrations of air pollutants is to ration allowable emissions into the atmosphere. The emission allowances then become important commercial and industrial commodities. A number of trading and allocation programs have evolved in recent years. These programs typically depend on continuous emission monitoring systems to provide a means of quantifying emissions and tracking and confirming the trades between sources and to account for allocations used. For example, in the acidic deposition control provisions of the 1990 Clean Air Act Amendments, CEM systems are required in this manner⁶. In this program fossil fuel fired power plants are allotted a specific number of allowances, one allowance being authorization to emit one ton of SO₂ per year. At the end of the year all emissions must have corresponding allowances. Another program is the RECLAIM program in the South Coast Air Quality Management District⁷ in which emissions are marketed for new facilities or expansions.

Emission Allowances

Sources covered by these programs may trade (buy and sell) emission allowances; however, the number of allowances available is limited. In order to build a new facility, or add to an existing one, sufficient allowances must be accumulated to account for the new sources by reducing emissions at other facilities or buying or trading for them. It is expected that, by reducing the number of allowances, the SO₂ emissions in the U.S. will be reduced by 10,000,000 tons per year from 1980 emission levels¹.

Allowance trading does not eliminate emission limits established by regulation. For example, a coal fired NSPS Subpart Da⁸ power plant with 90% scrubbing must still meet the 520 ng/J SO₂ emission limit regardless of the number of allowances they are able to secure.

Similar to the excess emission reporting requirements, CEM data are useful for assessing control equipment and regulatory efficiency. Data from the CEM can

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be used to determine the pollutant removal efficiency of control devices by combining either before and after control device readings or combining the exit readings with fuel and/or process parameter calculations. The trend in the CEM readings can also provide a means of tracking the control device maintenance or operational status.

Control Device Efficiency

The data from CEMs can also be used to coordinate emissions and ambient air quality modeling. The data can provide input into the dispersion and source-receptor models. These model based standards provide a link in the knowledge between the sources and ambient concentrations, thus strengthening the regulatory foundations for air quality improvement.

Dispersion Model Input Data

102.1 ANY CREDIBLE EVIDENCE (ACE)

Sources are required to meet the emission standards continuously; CEMs can provide data toward assuring that end. Although not all rules and regulations or permits require monitoring systems, the Compliance Assurance Monitoring (CAM) program of the Clean Air Act Operating Permits program (Title V) and Enforcement programs (Title VII) is expected to increase the use of CEMs.

Being developed coincident with the CAM rule, and under the CAA's enforcement mandates (Title VII), is a program of Any Credible Evidence (ACE)⁹. The ACE rule addresses evidentiary issues rather than affecting the emission limits.

This regulation removes the regulatory bar to the admission of non-reference method test data. Sources would be allowed to use cheaper, more flexible test methods for meeting permit compliance certification requirements¹⁰. For example, sources could rely on accurate data that already exists rather than performing additional, expensive, reference method tests if the existing data is acceptable to the regulatory agency. Conversely, the air pollution agencies can develop enforcement actions utilizing non-reference method and non-direct compliance CEMs test data.

Flexible Test Methods

Compliance Certification

The EPA, states, districts, and industries routinely rely on many types of information, including engineering calculations, indirect estimates of emissions, and direct measurement of emissions by a variety of means, in order to assess compliance with requirements¹¹. Where available, CEM data and well chosen parametric monitoring data, such as operating temperature and stack flow rate, can

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provide accurate data which can be referenced to the source's compliance emission limits and to regulatory standards.

Performance and reference method testing represents a few hours of data, whereas CEM data represents a continual data stream. In addition, performance testing often must be coordinated with the source beforehand, therefore the data represent the 'tuned-up' emissions rather than the ongoing emissions. The CEM data generally cover a greater percentage of a source's operation time and are more representative of a source's long term compliance status than sporadic performance testing.

103 PROGRAMS REQUIRING CEMS

An increasing number of programs, covering ever more sources and source categories, are requiring continuous emission monitoring. These programs may be federal, federal programs delegated to the states, federal mandates to the states, state, or district and local in nature.

103.1 NSPS

One of the oldest and most extensive continuous emission monitoring programs is the U.S.EPA New Source Performance Standards (NSPS) program (40 CFR 60)⁸. Numerous subparts of the regulation require sources to install, calibrate, maintain, and operate continuous emission monitors.

Direct Compliance CEMs

Compliance Indicating CEMs

In some of the NSPS subparts the CEMs are designated as direct compliance instruments (Table 103.1)¹² and, in other subparts, the CEMs are compliance indicating instruments (Table 103.2)¹². The direct compliance CEMs generate data that can be directly used to legally document the compliance status of the facility. The compliance indicating CEMs generate data that are an indication of the compliance status, but are insufficient for legal action.

California considers **all** CEMs to be direct compliance instruments. Therefore, CEMs at delegated NSPS sources in California would be considered to generate data to legally document the compliance status of the facility. The Any Credible Evidence (ACE) proposals¹¹ from the EPA are expanding the scope of use of CEMs at NSPS sources.

As the name implies, these requirements primarily affect newly constructed sources. They also apply if significant modifications of the source trigger the

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Table 103.1 Direct Compliance NSPS Monitoring¹²

NSPS Subpart	Affected Facility	Direct-Compliance Monitor	Averaging Period
Da	Electric Utility Steam Generator >73 MW heat input (250 million BTU/hr)		
	a) Solid Fossil Fuel	SO ₂ , NO _x	30 Day Rolling
	b) Liquid Fossil Fuel	SO ₂ , NO _x	30 Day Rolling
	c) Gaseous Fossil Fuel	SO ₂ (except when burning only natural gas), NO _x	30 Day Rolling
Db	Industrial-Commercial Institutional Steam Generators >29 MW (100 million BTU/hr)	SO ₂ , NO _x (except burning low-N ₂ fuels)	30 Day Rolling
Dc	Industrial-Commercial Institutional Steam Generator >2.9 MW (10 million BTU/hr) and <29 MW (100 million BTU/hr)	SO ₂	30 Day Rolling
Ea	Municipal Waste Combustor >225 Mg/day (250 T/day)	SO ₂	24 Hour Geometric
		NO _x	24 Hour Arithmetic
		CO	4 Hour Block Arithmetic (except mass burn rotary waterwall: 24 hour arithmetic)
J	Petroleum Refineries: FCC Catalyst Regenerator	SO ₂ , O ₂	7 Day Rolling
P	Primary Copper Smelters: Roaster, Smelting Furnace, or Converter (during compliance tests)	SO ₂	6 Hour
Q	Primary Zinc Smelters: Roaster (during compliance tests)	SO ₂	2 Hour
R	Primary Lead Smelter: Sintering Machine, Electric Furnace, or Converter (during compliance tests)	SO ₂	2 Hour
GG	Stationary Gas Turbines	NO _x (during performance tests, at other times water-to-fuel ratio indicates compliance)	N/A
RRR	Synthetic Organic Chemical Manufacturing Industry Reaction Processes	TOC	3 Hour
SSS	Magnetic Tape Coating Facilities:	TOC	3 Day Rolling
Any	Any	Opacity (source owners may submit opacity monitor data for direct compliance during performance tests)	6 minute

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Table 103.2 Compliance Indicating NSPS Monitoring¹²

NSPS Subpart	Affected Facility	Compliance Indicating Monitor	Averaging Period	Compliance Method
D	Fossil Fuel Fired Steam Generator >73 MW (250 million BTU/Hr)	Opacity SO ₂ NO _x	6 Minute 3 Hour 3 Hour	RM 9 RM 6 RM 7
Da	Electric Utility Steam Generator >73 MW (250 million BTU/Hr)	Opacity	6 Minute	RM 9
Db	Industrial-Commercial Institutional Steam Generator >29 MW (100 million BTU/Hr)	SO ₂ Opacity NO _x (low N ₂ fuels only)	3 Hour 6 Minute 30 Day Rolling	RM 6 RM 9 CEMS (direct compliance during performance tests)
Dc	Industrial-Commercial Institutional Steam Generators >2.9 MW (10 million BTU/Hr) and <29 MW (100 million BTU/Hr)	Opacity	6 Minute	RM 9
Ea	Municipal Waste Combustor >225 Mg/day (250 T/day)	Opacity	6 Minute	RM 9
F	Portland Cement Plants: Cement Kiln and Clinker Cooler	Opacity	6 Minute	RM 9
G	Nitric Acid Plants	NO _x	3 Hour	RM 7
H	Sulfuric Acid Plants	SO ₂	3 Hour	RM 6
J	Petroleum Refineries: Catalytic Cracking Unit Fuel Gas Combustion Unit Claus Sulfur Recovery Unit	Opacity CO SO ₂ or H ₂ S SO ₂ and O ₂ TRS and O ₂	6 Minute 1 Hour 3 Hour 12 Hour	RM 9 RM 10 RM 6 or 11 RM 6 RM 15
P	Primary Copper Smelter: Dryer Roaster, Smelting Furnace, or Converter	Opacity SO ₂	6 Minute 6 Hour	RM 9 CEMS (direct compliance during performance test)
Q	Primary Zinc Smelter: Sintering Machine Roaster	Opacity SO ₂	6 Minute 2 Hour	RM 9 CEMS (direct compliance during performance test)
R	Primary Lead Smelters: Blast Furnace, Dross Reverberatory Furnace, or Sintering Machine Discharge End Sintering Machine, Electric Furnace, or Converter	Opacity SO ₂	6 Minute 2 Hour	RM 9 CEMS (direct compliance during performance test)

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Table 103.2 Compliance indicating NSPS Monitoring (cont.)

NSPS Subpart	Affected Facility	Compliance Indicating Monitor	Averaging Period	Compliance Method
Z	Ferroalloy Production Facility: Submerged Electric Arc Furnace	Opacity	6 Minute	RM 9
AA	Steel Plants: Electric Arc Furnaces (1974 - 1983)	Opacity	6 Minute	RM 9
AAa	Steel Plants: Electric Arc Furnaces (1983 and after)	Opacity	6 Minute	RM 9
BB	Kraft Pulp Mills: Recovery Furnace	Opacity	6 Minute	RM 9
		TRS	12 Hour	RM 16
	Lime Kiln, Digester, Brown Stock Washer, Evaporator, Condensate Stripper	TRS	12 Hour	RM 16
CC	Glass Manufacturing Plants: Melting Furnace	Opacity	6 Minute	RM 9
HH	Lime Manufacturing Plants: Lime Kiln	Opacity (except when using a wet scrubber)	6 Minute	RM 9
NN	Phosphate Rock Plants: Dryer and Calciner	Opacity (except when using a wet scrubber)	6 Minute	RM 9
	Grinder	Opacity	6 Minute	RM 9
FFF	Vinyl and Urathane Coating and Printing: Rotogravure Printing	VOC	3 Hour	RM 25A
LLL	Onshore Natural Gas Processing: Sulfur Recovery Oxidation Control or Reduction Control Plus Incineration	SO ₂ or SO ₂ and TRS	24 Hour	RM 6 or RM6 and 16A
	Reduction Control	TRS	24 Hour	RM 15
UUU	Calciners and Dryers in Mineral Industries	Opacity	6 Minute	RM 9

rules. An existing source, constructed before the date the NSPS rules were proposed, are subject to other state and district rules.

103.2 NESHAPS

Four subparts of the National Emission Standards for Hazardous Air Pollutants¹³ (NESHAP, 40 CFR 61) require CEMs (Table 103.3). Since these sources have

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Table 103.3 NESHAP Monitoring¹³

NESHAP Subpart	Affected Facility	Monitor Required	Averaging Period	Compliance Method
F	Ethylene Dichloride Purification Oxychlorination Reactor Vinyl Chloride Plant PVC Reactor Mixing, Weighing, and Holding Containers Control Systems to Which Reactor and Fugitive Emissions are Ducted	Vinyl Chloride	3 Hour	Method 106
N	Glass Melting Furnace Opacity	Opacity	6 Minute	Method 108
O	Copper Converter	Opacity	1 Hour	Method 5
P	Metallic Arsenic Production and Arsenic Trioxide Plants	Opacity	6 Minute	Inspection, Maintenance, and Housekeeping Plan

Opacity Monitoring

the potential to emit hazardous air pollutants, it is especially important to control excess emissions. In several of the subparts for opacity monitoring is used as an indicator of the level of emissions of the hazardous components. Therefore, excess opacity emissions take on added significance.

HAPs

The NESHAP program is primarily a technology based program to limit the emissions of 190 hazardous air pollutants (HAPs). To implement the program, maximum achievable control technology (MACT) standards will be developed on a source category basis. Additional HAP monitoring requirements will continue to be developed.¹⁴ The ARB Compliance Assistance Section is currently developing the Toxics Enforcement Manual to fully discuss the MACT programs.

103.3 ACID DEPOSITION

Title IV of the Clean Air Act Amendments (CAAA) of 1990 authorized the EPA to establish the Acid Rain Program.⁶ The Acid Rain Program's purpose is to prevent the adverse effects of acidic deposition by setting emission limitations to reduce the precursor emissions. This program applies to fossil fuel fired electric utility boilers and turbines. The CEM regulations, promulgated under 40 CFR 75 (Part 75), apply to existing as well as new sources.

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The Acid Rain Program regulations control the emission of SO₂, NO_x, CO₂, and opacity and allow the trading of SO₂ emission allowances. To obtain SO₂ and NO_x mass emission data, diluent (oxygen or carbon dioxide) and stack gas velocity must be monitored in addition to the pollutant concentration.

Diluent and Velocity Monitoring

The Part 75 monitoring requirements are similar to those for NSPS; however, in general, the Part 75 requirements are more stringent. For example, all monitoring data must be submitted under Part 75 (rather than just a summary) and the relative accuracy of the systems must be less than 10% rather than the 20% allowed by NSPS.

In addition to the testing of the CEM system, an Acid Rain Program monitoring system must pass a certification approval process. After conducting the performance tests, an application for certification is submitted. The EPA then will issue a notice of approval or disapproval within 120 days. If an audit of the monitoring system or the application for certification shows that the CEM system does not meet the requirements of the performance specification, then a notice of disapproval will be issued and the system certification will be revoked. The facility must repeat the certification tests within 30 days after the issuance of a notice of disapproval.

Certification Approval

If the monitoring system fails a periodic quality assurance audit the system is deemed out-of-control and must be repaired and the audit repeated. During the out-of-control period the data from the system cannot be used and one of the "missing data" procedures must be followed.

Missing Data

103.4 STATE IMPLEMENTATION PLAN MONITORING

All states are required to submit a State Implementation Plan (SIP) to the U.S.EPA for approval. The SIP provides a plan to attain, maintain, and enforce the National Ambient Air Quality Standards (NAAQS) in each air quality control region in the state.¹⁵

Among the many provisions contained in the SIP requirements of 40 CFR 51 is the stipulation in Section 51.214 that each SIP contain legally enforceable procedures requiring certain categories of existing sources to continuously monitor emissions. Appendix P of Part 51¹⁵ lists the affected source categories (Table 103.4) and gives the types of monitoring required, the performance specifications, and the minimum data and reporting requirements.

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Table 103.4 Existing Source Categories Required to Monitor¹⁵

Source Category	Pollutants	Comments
Fossil Fuel Fired Steam Generators, Annual Capacity Factor > 30 %	Opacity	> 73 MW (250 million BTU/Hr) Exempt if Burning Natural Gas Exempt if Burning Oil (or Oil and Gas) and Meets Particulate and Opacity Standards Without Control Equipment and Source Never Found in Violation
	SO ₂	> 73 MW (250 million BTU/Hr) Source Has Control Equipment for SO ₂
	NO _x	> 293 MW (1000 million BTU/Hr) Located in NO _x Nonattainment Area Exempt if NO _x Emission Level is 30 % or More Below Emission Standard
Nitric Acid Plants	NO _x	> 270 Mg/day (300 T/day) Located in a NO _x Nonattainment Area
Sulfuric Acid Plants	SO ₂	> 270 Mg/day (300 T/day)
Fluid Catalytic Cracking Units at Petroleum Refineries	Opacity	> 20,000 Barrels/day

There are four categories of existing stationary sources designated in Appendix P as being subject to continuous emission monitoring. State regulations can require continuous emission monitoring at additional source categories. The 40 CFR 51 Appendix P source categories are:

- Fossil fuel fired steam generators having a capacity factor above 30% and a heat input of greater than 73 MW (250 million BTU/hr);
- Nitric acid plants of greater than 270 Mg/day (300 T/day) capacity (expressed as 100% acid) and located in NO_x nonattainment areas;
- Sulfuric acid plants of greater than 270 Mg/day (300 T/day) production capacity (expressed as 100% acid);
- Fluid catalytic cracking unit (FCCU) catalyst regenerators at petroleum refineries, for FCC units of greater than 20,000 barrels/day fresh feed capacity.

These Appendix P mandated monitors may be either direct compliance instruments or compliance indicating instruments.

Appendix P Source Categories

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If the state regulations are part of the EPA approved SIP, the CEM requirements become federally enforceable; however, these state mandated requirements may still be more stringent than the federal monitoring program requirements. Table 103.5 shows the difference between new and existing source monitoring requirements.

103.5 PERMITS

Continuous emission monitors are sometimes required by various types of permits (e.g. state/district permits, PSD permits, Title V operating permits, etc.). These monitors are also sometimes concurrently required by regulation (e.g., NSPS, SIP, state and local regulations, etc.). Permit monitoring provisions may be more stringent than the regulatory requirements.

PSD, Title V, State/District

103.5.1 Prevention of Significant Deterioration Permits

The Prevention of Significant Deterioration (PSD) program addresses the need to maintain air quality in areas meeting the NAAQS. The PSD permit may require monitoring beyond that required by other regulatory and permit programs

Table 103.5 Differences Between New and Existing Source CEM Requirements

Source Category	Pollutant to be Monitored	Plant Capacity	
		New Sources	Existing Sources
Fossil Fuel Fired Steam Generators	Opacity	> 73 MW	> 73 MW
	SO ₂		
	NO _x	> 73 MW and emissions > 70% of standard	> 293 MW and emissions > 70% of standard
Sulfuric Acid Plants	SO ₂	All NSPS sources	> 270 Mg/day
Nitric Acid Plants	NO ₂	All NSPS sources	> 270 Mg/day
Petroleum Refineries Catalyst Regenerators for Fluid Bed Catalytic Cracking Units	Opacity	All NSPS sources	> 20,000 BBL/day

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to assure that a source does not significantly impact air quality in an otherwise clean air region.

103.5.2 Title V Permits

Source emission measurement is particularly important for facilities with emission levels close to the major source threshold which triggers the Title V requirements.¹⁶ If emissions are above the major source threshold, then increased compliance activity is required. Facilities designated as major sources must comply with stringent Title V permit requirements. For facilities subject to Title V, emissions measurements may be the best way to accurately characterize and speciate emissions from the processes and certify compliance with the applicable requirements. The Title V program is tightly linked with the Compliance Assurance Monitoring (CAM, Section 105) and Any Credible Evidence (ACE, Section 102.1) programs.

103.5.3 State and District Permits

In California, both state and district regulations require that emissions be monitored. Since stationary source regulation in California is the purview of the districts, most of the permit-based CEM requirements arise from the district rules.

Many districts, especially the smaller ones, reference their CEM requirements to other delegated federal and state programs (e.g. NSPS, etc.). However, other districts have derived their own substantial CEM rules. For example, South Coast Air Quality Management District Rule 218¹⁷ requires stack monitoring of NO_x, SO₂, and CO₂ or O₂ at large steam generating plants; NO_x at nitric acid plants; SO₂ at sulfuric acid plants, carbon monoxide boilers, or furnaces of the regenerators of fluid catalytic cracking units and fluid cokers; and SO₂ at sulfur recovery plants. CEMs may also be required at sources emitting 900 Mg/yr or more CO or 90 Mg/yr of any other pollutant. Also, as part of Rule 218, there are monitoring system approval mechanisms, performance standards, and reporting requirements.

The South Coast Air Quality Management District also has an incentives marketing program (RECLAIM - Regional Clean Air Incentives Market) for sulfur oxides and nitrogen oxides which contains CEM provisions⁷.

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The California ARB has several provisions in the Health and Safety Code¹⁸ (H&SC) allowing or mandating the use of CEMs. Section 42303 allows for the disclosure of the nature, extent, quantity, or degree of air contaminants from a permitted source. Section 41511 gives the state or district the power to require sources to monitor emissions. Chapter 5 of the Health and Safety Code (Sections 42700 - 42708) details more about monitoring and monitoring equipment at sources and encourages the districts to require monitoring at sources emitting more than 91 Mg/yr (100 tons/yr) of nonmethane hydrocarbons, oxides of nitrogen, oxides of sulfur, reduced sulfur compounds, or particulate matter; or more than 910 Mg/yr (1,000 tons/yr) of carbon monoxide. Finally, Section 39616(c)(2) requires that market based incentive programs (such as the SCAQMD's RECLAIM) must provide a level of enforcement and monitoring to ensure compliance with emission reduction requirements. The text of selected H&SC rules is in Appendix G of this manual.

California H&SC Monitoring Provisions

103.6 RCRA HAZARDOUS WASTE INCINERATION

The Resource Conservation and Recovery Act (RCRA) has several requirements for continuous emission monitoring for facilities burning hazardous wastes. Hazardous wastes can either be burned in incinerators (covered by 40 CFR 264) or in boilers and furnaces (covered in 40 CFR 266). Carbon monoxide emissions are used as a surrogate for the combustion efficiency, hence, CO monitoring is required of all hazardous waste combustors. In incinerators, CO and stack gas velocity are measured and in boilers and industrial furnaces (BIF), CO, O₂, and hydrocarbons are required to be monitored (Table 103.6). New technologies for monitoring of additional parameters in the stack gases continue to be developed and may be required by permit provisions. In addition to emission monitoring, many RCRA sources are required to conduct intensive reference method testing to assure that excess emissions of toxic compounds, chlorinated compounds, metals, etc. are not occurring.

CO As An Indicator of Combustion Efficiency

Table 103.6 RCRA Monitoring Requirements

Subpart	Source Category	Source Facility	Pollutant
264	Hazardous Waste Incinerators	Incinerators	CO Velocity
266	Boilers and Industrial Furnaces Burning Hazardous Wastes (BIF Rules)	Boiler, Furnace, or Kiln	CO O ₂ THC

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103.7 DISCRETIONARY MONITORING PROGRAMS

An air control agency may have a great deal of discretionary authority to incorporate continuous emission monitoring into their regulatory framework. The use of discretionary authority allows fairness to be applied in regulatory programs. For example, by installing a CEM system to assure continuous compliance, an agency may be willing to allow a source time to design and install new control equipment or continue to operate while upgrading facilities. However, discretionary authority must be used with care since it can lead to arbitrary regulation, as it does not have the extensive public oversight that rule making does.

Discretionary CEM programs can include:²

- **Variances** - Under special circumstances a temporary authorization to emit (variance) may allow a source to discharge pollutants in excess of the level allowed by the standard that may otherwise may apply. A variance is generally issued for a specific time period, provided the source corrects the problem and meets the standard by the end of the period. Special monitoring requirements are often included in the provisions of such variances. An important caveat to variances is that, while they provide relief from state and local enforcement actions, they do not pertain to federal regulations and enforcement actions.
- **Orders** - Orders are legal directives that are generally issued after conducting public hearings. Orders to comply with state agency requirements can be issued to a source under the enforcement authority given in Section 113 of the Clean Air Act. There are several types of orders: 1) administrative orders, 2) delayed compliance orders, and 3) court orders. These differ with respect to the type of legal authority it takes to issue them.
- **Agreements** - Agreements are a result of negotiations between a facility and the air control agency. Again, agreement is a way to get a source into compliance with applicable regulations. Consent decrees, stipulation agreements, and court settlements are some example agreement types.
- **Permits** - To a certain extent, a permit can be thought of as a discretionary program. In the course of issuing a permit an agency has a great deal of flexibility and authority for reaching its goals. The agency has the ability to incorporate CEMs as part of these actions.

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103.8 IMPLICIT PROGRAMS

Implicit programs are implemented through guidance documents that are developed by the regulatory agency, such as a "CEM Quality Assurance Manual" or a "CEM Guidance Document", that may contain specific information on how monitors should be installed, certified, calibrated, audited, etc. These documents may be incorporated into permits or agreements by reference; i.e. a permit provision may state that CEM operation must follow the "CEM Guidance Document" procedures.

Incorporation
by Reference

These documents provide needed guidance; however, like many discretionary programs, they are not subject to agency rule-making procedures. They may receive little outside input or public comment before being implemented. Since they may become part of an implicit CEM requirement, care must be taken when writing guidance documents, etc. to avoid inadvertent requirements being placed on facilities.

104 PREDICTIVE EMISSION MONITORING (PEMS)

An alternative to gas analyzer based continuous emission monitoring systems are predictive emission monitoring systems. Instead of actually measuring the emissions, a PEMS uses a computer program to predict the emissions based on measured ambient and operational parameters. For steady-state sources with homogeneous fuels, for which the parameters can be well characterized, the PEMS may present a viable alternative to a CEM system. The PEMS may be capable of producing the reliable and timely data required by the compliance assurance monitoring program.

Steady State
Source

Homogeneous
Fuels

Well
Characterized
Operation

The most common type source for which PEMS have been used is the stationary gas turbine.¹⁹ Gas turbines typically use clean, well characterized fuels (pipeline grade natural gas) and are most commonly operated at a constant rate. Both of these factors make PEMS a viable monitoring solution.

A predictive continuous emission monitoring system on a gas turbine generally contains the following major subsystems: ambient temperature, humidity, and pressure sensors, turbine parameter sensors, fuel sensors, and a computer programmed to calculate the emissions.²⁰ Figure 104.1 graphically illustrates the PEM concept.

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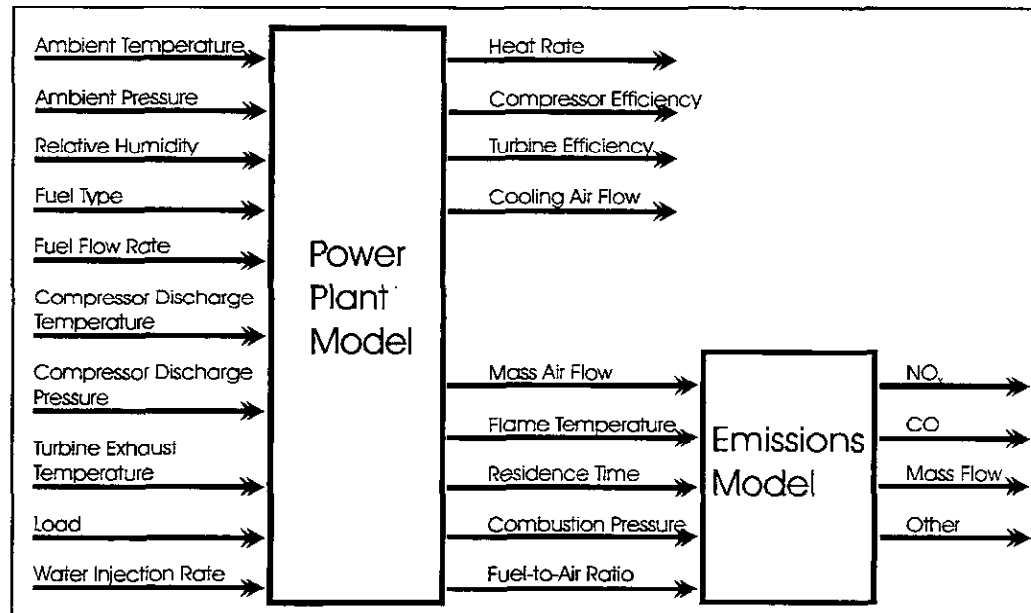


Figure 104.1 PEM Conceptual Diagram

It has been estimated²¹ that gas turbine performance data are fairly accurate to around plus or minus one percent. The total PEM system aggregate accuracy can then be expected to be about plus or minus five percent. In Practice, PEMs predictions differ from actual measurements by between 1.52% to 12.8%.¹⁹

For a source on which a PEM is appropriate, it may do as good, or better, a job reporting emissions as a gas analyzer CEM and cost less to install and operate.

The predictive emission monitors are not immune from operational or emission reporting requirements. The quarterly summary and Excess Emission Reports (EERs) still must be submitted. The systems must also pass the quarterly and annual audits and tests.

With continually improving sensors, computers, and programming (in addition to improving technology and knowledge of source dynamics) predictive emission monitoring may well become a common alternative practice in the future.

105 COMPLIANCE ASSURANCE MONITORING (CAM)

The Compliance Assurance Monitoring (CAM) regulations respond to a mandate in the Clean Air Act Amendments (CAAA) of 1990.³ The 1990 CAAA contain

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several provisions that require sources to conduct monitoring and to make compliance certifications. The CAM approach is intended to address the requirements of Title VII in the CAAA (enforcement provisions) that the EPA promulgate enhanced monitoring and compliance certification requirements for major sources. The CAM rules also are intended to satisfy the requirements for monitoring and compliance certification in the Part 70 operating permits program of Title V. The CAM monitoring is intended as the mandated enforcement and compliance certification tool.

Title VII

Title V

The Title V operating permit has been streamlined to only include the important monitoring elements. The permit will include the facility's approach to monitoring, the acceptable range of control device operation, and the basic quality assurance criteria. The detailed monitoring operations are left to the facility.

Draft CAM rulemaking affecting 40 CFR 64, 70, and 71 was proposed in August 1996. The final promulgation was in October 1997.^{5,22}

The CAM rule applies to facilities that operate emission control devices in accordance with federally enforceable regulations issued prior to 1990.⁴ These federally enforceable regulations are not limited to EPA regulations, they also include any regulations (including state, and district regulations) that pertain to the Title V operating permit.

The time frame for compliance with the CAM rule is between 180 days from rule promulgation to more than five years. For new sources and those that have not yet been determined to have complete Title V permit applications within 180 days after rule publication, the rule becomes effective within 180 days. For sources that have an existing Title V operating permit or have received a determination of completeness by the deadline date, the rule becomes effective as part of the renewal of the operating permit; i.e. five or more years in the future.

With the 1990 Clean Air Act Amendments, the EPA incorporated "directly enforceable monitoring" into all emission regulations. Therefore, this rule does not apply to facilities that are subject to EPA regulations issued after 1990. It is possible that some portion of a facility may operate control devices in order to comply with emission standards issued prior to 1990. In this case, those portions of the facility must comply with the requirements of the CAM rule.

The CAM rule does not necessarily require the installation of CEMs. The rule focuses on improving current monitoring requirements and allows facilities to

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Indicator Ranges

develop "operation indicator ranges" for control equipment. The ranges represent air pollution control practices that minimize emissions and provide a reasonable assurance of compliance. Indicators of performance may include:

- Directly measured or predicted emissions
- Process and control device parameters
- Recorded findings of inspection and maintenance activities

Testing and Justification of Indicators

Although a source test is not required to demonstrate the performance indicators, if a test is conducted for other reasons, it should be used to confirm the indicator values. Otherwise, a detailed justification of the proposed indicators must be submitted when the CAM plan is submitted for approval.

Units operating within their CAM parameters are presumed to be in compliance. If the ranges are exceeded, immediate corrective action is required.

Pre-Control Major Source

In order to focus the requirements of the CAM rule on preventing pollution control problems before they occur, the EPA determined that the rule would only apply to those units at sources with control devices (active controls.) Whether an emission unit is subject to the rule is defined by the level of emissions that would occur without the control device in operation (i.e. precontrol emissions.) If the unit has precontrol emissions of the applicable air pollutant that are equal to or greater than 100% of the amount, in tons per year, required for the source to be classified as a major source, the CAM rule applies.

Approximately 10% of processes at major industrial facilities that are subject to air pollution emission standards are fitted with control equipment. Of those facilities, approximately 60% are covered by the CAM rule. Altogether, the control devices monitored under the CAM rule will control over 97% of the total emissions from all facilities utilizing air pollution control devices and receiving Title V operating permits^{4, 23}.

Design, Reporting, Recordkeeping

The CAM rule establishes criteria that define the design of the monitoring program, reporting, and recordkeeping that should be conducted by a source to provide a reasonable assurance of continuous compliance with emission limitations and standards. These criteria will focus on:³

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Continuous Emission Monitoring

- Enhancing the current operation and maintenance (O&M) monitoring requirements;
- Define the applicable monitoring approach;
- Maximum duration of discrepancies from established pollution control indicator ranges that represent acceptable control performance;
- The obligation to complete corrective actions indicated by the monitoring results; and
- How the data are to be used in the annual compliance certification.

The principal monitoring approach for any operation or facility will depend on the control technology used to meet the emission limits. Sources with active control devices (Table 105.1)²⁴, such as scrubbers, will be required to have CAM plans, while the sources controlled by passive techniques (Table 105.2)²⁴ - such as combustion controls, design criteria, or work practices - may only need to supply proof of good operation and maintenance practices through appropriate recordkeeping.

The CAM rule includes Title V compliance certification language that allows the source owner or operator to use the compliance assurance monitoring data to establish their compliance status with the permit terms and provisions. They can use this information to certify their facility complies with air pollution control requirements of the Clean Air Act.

Facility owners and operators to periodically (at least every six months) report on the compliance status for each requirement in the permit and note any periods of operation outside the established CAM indicator ranges. These compliance certification reports, along with the monitoring results, are valuable tools for the enforcement agency to use in identifying facilities with significant compliance problems and in deciding how to target limited enforcement resources.

A facility that already must maintain continuous emission monitoring is not required to install additional CAM rule related monitoring. The existing monitoring may be used to fulfill the CAM rule monitoring. CAM language can be inserted into existing certification reports to satisfy CAM certification requirements.

Active vs Passive Controls

Compliance Certification Reports

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Table 105.1 Active Control Devices Satisfying Part 64 Definition for Applicability²⁴

AIRS Code	Description of Control Method
001 002 003	Wet Scrubber: High Efficiency Medium Efficiency Low Efficiency
004 005 006	Gravity Collector: High Efficiency Medium Efficiency Low Efficiency
007 008 009	Centrifugal Collector: High Efficiency Medium Efficiency Low Efficiency
010 011 012	Electrostatic Precipitator: High Efficiency Medium Efficiency Low Efficiency
013	Gas Scrubber, General
014 015	Mist Eliminator: High Velocity Low Velocity
016 017 018	Fabric Filter: High Temperature Medium Temperature Low Temperature
019 020	Catalytic: Afterburner Heat Exchanger
021 022	Direct Flame: Afterburner Heat Exchanger
023	Flaring
026	Flue Gas Recirculation
028 032	Injection: Steam or Water Ammonia
034 035 036 037 038	Scrubbing: Wellman - Lord / Sodium Sulfite Magnesium Oxide Dual Alkali Citrate Process Ammonia
039	Catalytic Oxidation - Flue Gas Desulfurization

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Table 105.1 Active Control Devices Satisfying Part 64 Definition for Applicability (cont.)

AIRS Code	Description of Control Method
040	Alkalized Alumina Vapor Space Tank
041 042	Limestone Injection: Dry Wet
043 044	Sulfuric Acid Plant: Contact Process Double Contact Process
045	Sulfur Plant
047	Vapor Recovery System
048	Activated Carbon Adsorption
049	Liquid Filtration System
050 051	Gas Absorber Column: Packed Tray Type
052	Spray Tower
053 055	Scrubber: Venturi Impingement Plate
056 057	Dynamic Separator: Dry Wet
058 059 063 064	Filter: Mat or Panel Metal Fabric Filter Screen Filter: Gravel Bed Annular Ring
065	Catalytic Reduction
066	Molecular Sieve
067 068 069 070	Scrubbing: Wet Lime Slurry Alkaline Fly Ash Sodium Carbonate Sodium - Alkali
071	Fluid Bed Dry Scrubber

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Table 105.1 Active Control Devices Satisfying Part 64 Definition for Applicability (cont.)

AIRS Code	Description of Control Device
072 073 074	Condenser: Tube and Shell Refrigerated Barometric
075 076 077	Cyclone: Single Multi without Fly Ash Reinjection Multi with Fly Ash Reinjection
079	Dry Electrostatic Granular Filter
080	Chemical Oxidation
081	Chemical Reduction
082	Ozonation
083	Chemical Neutralization
084	Activated Clay Adsorption
085	Wet Cyclonic Separator
086	Water Curtain
087	Nitrogen Blanket
098	Moving Bed Dry Scrubber
101	High Efficiency Particulate Air (HEPA) Filter
107	Selective Noncatalytic Reduction (SNCR) for NO _x

If the control equipment is found to be operating outside the acceptable ranges, the owners and operators are required to take prompt corrective action to make the necessary adjustments or repairs to the control equipment. They must also notify the state and local authorities of any excess emissions.

If persistent control device problems occur, and the monitoring data indicate that the total duration of excursions or the total number of monitoring periods with excursions exceeds a threshold value, a quality improvement plan (QIP) is required. The permitting authority must be notified within two working days that

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**Table 105.2 Passive Control Devices Not Satisfying Part 64
Definition for Applicability (Subpart C May Apply)²⁴**

AIRS Code	Description of Control Method
000	No Equipment
024	Modified Furnace / Burner Design
025	Staged Combustion
027	Reduced Combustion Air Preheat
029	Low Excess Air Firing
030	Fuel - Low Nitrogen Content
031	Air Injection
033	Control of Percent O ₂ in Combustion Air
046	Process Change
054	Process Enclosed
060	Process Gas Recovery
061 062	Dust Suppression: Water Spray Chemical Stabilizers / Wetting Agents
078	Baffle
088	Conservation Vent
089	Bottom Filling
090 091 092	Conversion to: Variable Vapor Space Tank Floating Roof Tank Pressurized Tank
093	Submerged Filling
094	Underground Tank
095	White Paint
096	Vapor Lock Balance Recovery
097	Install Secondary Seal for External Floating Roof Tank

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**Table 105.2 Passive Control Devices Not Satisfying Part 64
Definition for Applicability (Subpart C May Apply) (cont.)**

AIRS Code	Description of Control Method
102 103 104	Coatings: Low Solvent Powder Water Borne
105	Process Modification: Electrostatic Spraying
106 108	Dust Suppression: Physical Stabilization Traffic Control

the threshold was triggered and a QIP⁵ is to be developed. The facility owner or operator has 180 days to develop and implement the QIP. The QIPs must specify procedures for evaluating the cause of the control device performance problems that led to the excursions. Based on the evaluation, the QIP must include preventive maintenance practices, process operation changes, appropriate improvements to control methods, and other steps to correct the control performance and also include more frequent or improved monitoring.

106 LEGAL REQUIREMENTS

Continuous emission monitors are an important part of the air pollution prevention and compliance structure. They form an integral part of enforcement and inspection strategies. A number of provisions of the California Health and Safety Code allow for, or require, CEMs for determination of emissions compliance.

106.1 CALIFORNIA HEALTH AND SAFETY CODE

The following is a list of informative headings of those sections of the California Health and Safety Code (H&SC)¹⁸ that provide legal guidance to the California Air Resources Board and local air pollution control or air quality management districts in performing their assigned duties. The text of these sections is included in Appendix G of this manual. For other legal requirements, consult the complete H&SC or local and federal regulations.

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39000	Legislative Findings, Environment
39001	Legislative Findings, Agency Coordination
39002	Local and State Agency Responsibilities
39003	ARB Responsibilities
40000	Local/State Responsibilities
40001	Adoption and Enforcement of Rules and Regulations
40702	Adoption of Rules and Regulations
41509	No Limitation on Powers to Abate Nuisance
41510	Right of Entry with Inspection Warrant
41700	No Person Shall Discharge Pollutants (Public Nuisance)
41701	No Emissions Shall Exceed Ringlemann 2 (Opacity Standards)
42300	District Permit System
42301	Requirements For Permit Issuance
42301.6	Permit Approval: Powers and Duties of Air Pollution Control Officer
42301.7	Air Contaminants, Threatened Release
42303	Air Contaminant Discharge: Information Disclosure
42303.5	False Statements in Permit Applications
42304	Permit Suspension (Failure to Supply Information)
42352	Findings Required for Issuance of Variance
42400	General Violations, Criminal
42400.1	Criminal Penalties, Negligence, \$15,000/Day and/or Nine Months Jail Time (Maximum)
42400.2	Criminal Penalties, Knowingly, \$25,000/Day and/or One Year Jail Time (Maximum)
42400.3	Criminal Penalties, Willfully, \$50,000/Day and/or One Year Jail Time (Maximum)
42401	Violating Order of Abatement, Civil
42402.1	General Violations, Civil
42402.1	Civil Penalties, Negligence, \$15,000/Day
42402.2	Civil Penalties, Knowingly, \$25,000/Day
42402.3	Civil Penalties, Willfully, \$50,000/Day
42402.5	Civil Penalties, Administrative
42403	Civil Penalties, Relevant Circumstances
42404.5	Statute of Limitations for Civil Actions
42450	Orders of Abatement: District Board; Authority; Notice and Hearing
42700	Legislative Findings and Declarations (Monitoring Devices)
42701	Emissions Monitoring Devices
42702	Availability of Monitoring Devices

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42703	Reimbursement for Actual Testing Expenses
42704	Determination of Availability; Revocation or Suspension
42705	Records
42706	Report of Violation of Emission Standard
42707	Inspection; Fees
42708	Powers of Local or Regional Authority

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200 CEM THEORY AND DESIGN

Continuous Emission Monitoring

There are a number of instrument types and designs that have been developed for continuous emission monitoring systems. Continuous emission monitors are approved on a case-by-case basis and only after that specific application has been tested and demonstrates that it performs according to the EPA specifications.

CEM Approval

Ambient air monitor designs are approved generically, greatly simplifying their implementation process. After an ambient monitor design has been tested and meets the EPA criteria, that monitor can be deployed in the field wherever needed without further testing. However, each emission source on which a CEM is installed can be quite different from all others; therefore, generic approval of CEMs is impractical. The testing procedures are detailed in 40 CFR 60 Appendix B and will be discussed in more detail later in this manual.

201 TYPES OF CEM SYSTEMS

There are three general classes of continuous emission monitoring systems: 1) extractive, 2) in-situ, and 3) predictive¹. Each of these classes can be further divided into more specific monitor types (Figure 201.1). In addition to these three classes of CEMs, visible emission evaluation (VEE), manual source testing,

Extractive In-Situ Predictive

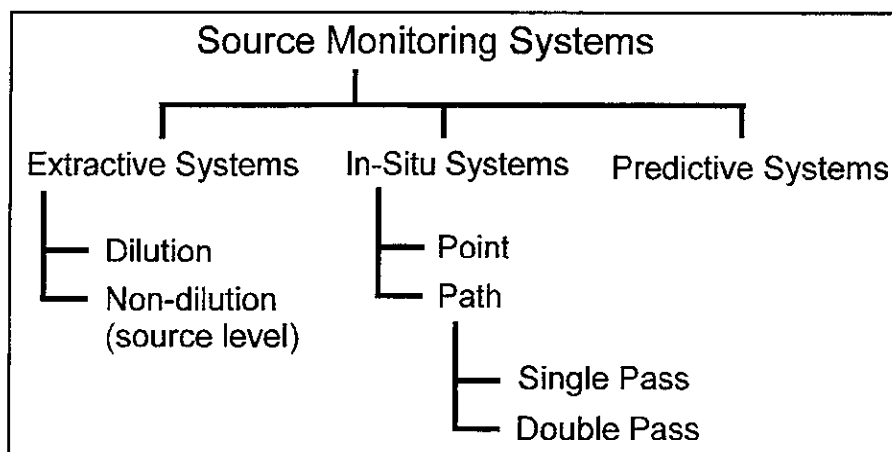


Figure 201.1 Continuous Emission Monitoring Systems

and remote sensing can also be considered source emission monitoring techniques. This manual concentrates on the extractive and in-situ CEM systems with some discussion of predictive monitoring.

200 CEM THEORY AND DESIGN

Preference of in-situ or extractive monitors is a continuing matter of discussion. Since CEMs are highly application specific, there is no a priori "best" system. With advances in monitoring technology and techniques constantly occurring, overall industry preferences often track with the changing regulatory requirements and evolving technology. The quality of data reported is much more closely related to system maintenance than the type of CEM used.

A wide variety of instrument types and designs are available for CEM applications which can fulfill the monitoring requirements. Matching the CEM system design to the emission source must account for characteristics of the CEM design, the source properties, regulations to which the source is subject, and the required reporting to the local control agency.

201.1 IN-SITU SYSTEMS

In Stack Analysis

In-situ CEMs are those that analyze pollutant concentrations in place in the stack. These systems have fewer parts than extractive systems and so capital expenses are often lower. Also, fewer system parts implies less equipment to maintain. Maintenance, however, can be more difficult since it occurs on the stack, exposed to weather. The equipment is also exposed to harsher conditions, both from the standpoint of being exposed to weather conditions and being exposed to the harsher industrial environment on the stack. The entire in-situ monitor must withstand the corrosive stack gases and the vibration on the stack, whereas most of the equipment of an extractive CEM is off the stack in an equipment room on the ground. Table 201.1 illustrates some of the advantages and disadvantages of in-situ and extractive CEM systems.

Since the in-situ monitors analyze emissions directly in place, there is no gas conditioning such as temperature control or moisture removal. If gas conditioning is required, an extractive system must be used.

Point Path

There are two basic types of in-situ CEM systems: point and path measurements (Figure 201.2). The point measurements are taken from a single point in the stack. The path measurements are taken as an integration across the stack.

201.1.1 Point Measurement In-Situ CEMs

Point measurement CEMs measure the gas directly at a small point where the probe is installed in the stack. In the most common configuration of a point CEM (Figure 201.3) the stack gases diffuse into a cavity at the end of the probe.

Table 201.1
Advantages and Disadvantages of In-Situ and Extractive Systems²

System Type	Advantages	Disadvantages
Path in-situ	Fast response time No sample transport or conditioning Gas measured on wet basis Simple, less expensive installation Less equipment to buy and maintain	Potential interference by particulate or droplets Gas measured on wet basis, moisture content must be assumed for dry basis reporting Sometimes cannot locate equipment downstream of sorbent injection or spray dryer systems Analyzers exposed to harsh operating conditions and vibrations Limited choice of analyzer Cannot calibrate analyzer when process is operating
Point in-situ	Fast response time No sample transport or conditioning Gas measured on wet basis Simple, less expensive to buy and maintain	Representative sample difficult to obtain in some situations Gas measured on wet basis Vibration sensitive Access for maintenance can be difficult Limited choice of analyzer
Source level extractive	Allows widest selection of analyzer technologies Can analyze at ambient conditions for which more reference data is available Can combine more than one analyzer (e.g. GC and FID) Can remove interfering substances before measurement Gas measured on dry basis Analyzers can be installed in an accessible, clean environment Multiprobe capability for representative sample	Sample transport and conditioning system is expensive to install and operate and has high power requirements Sample transport and conditioning system has potential for pluggage, leaks, and condensation problems (both water and acid) Gas conditioning is often required Gas measured on dry basis May inadvertently remove substances of interest Condensed water and/or filter residues may need to be analyzed
Dilution extractive	Wide selection of analyzers Can analyze at ambient conditions One dilution system can serve several analyzers Analyzers can be installed in an accessible, clean environment Gas measured on wet basis Multiprobe capability Heated sample lines and moisture removal systems not necessary	Measurement accuracy and data precision problems may occur with highly diluted samples Dilution system may not work on high moisture flue gas Gas is measured on a wet basis; this may not be a problem if CO ₂ is used as the dilution gas Requires additional calibration for the dilution system

200 CEM THEORY AND DESIGN

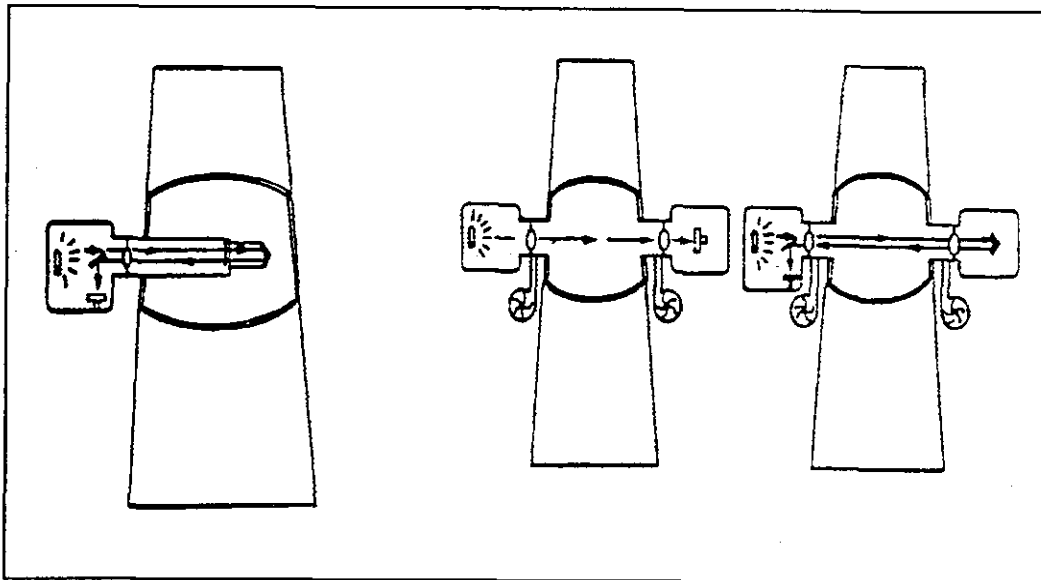


Figure 201.2 Basic In-Situ CEM Types: Point; Single, Double Path³

A ceramic filter is usually installed to prevent particulate from entering the measurement cavity. A baffle plate can be used to deflect particulate, protecting the probe and filter from much of the particulate.

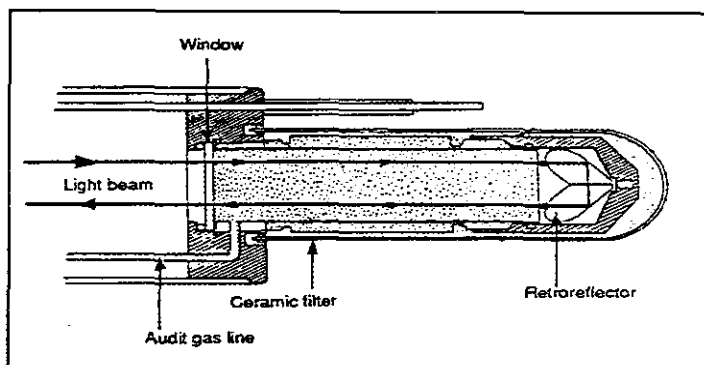


Figure 201.3 Point In-Situ Sample Probe³

Two major factors affect the accuracy of point measurements: the location of the probe and its ability to withstand the stack conditions. The probe must be located at a point where the concentrations being sampled are representative of the stack emissions. Secondly, the analyzer must be able to accurately measure the gases under the harsh conditions existing in the stack.

As with all monitoring systems, the point measurement in-situ CEMs must be able to be calibrated at the point of measurement. This is usually accomplished by injecting calibration gas into the probe cavity via the audit gas line, displacing the stack gas with the calibration gas. Some older systems cannot meet this requirement and so cannot meet current EPA specifications.^{4,5}

201.1.2 Path Measurement In-Situ CEMs

Path measurement, or cross stack CEMs average the emission concentrations across the width of the stack. The path in-situ CEMs can be either single pass, in which the transmitter and receiver are on opposite sides of the stack, or double pass, in which the transmitter and receiver are both contained in the same "transceiver" device. In a double pass monitor a mirror reflects the measurement beam back across the stack. A double pass monitor has twice the analytical pathlength, therefore is more sensitive than a single pass instrument.

An inherent drawback of path in-situ CEMs is the inability to calibrate the system during normal process operation. Since the EPA requires that all CEMs be calibrated daily,^{4,5} systems that cannot be calibrated are unacceptable. Double pass instruments often incorporate a zero mirror and gas cell in the transceiver. This configuration presents an acceptable (although not ideal) solution. In single pass instruments it is much more difficult to devise an acceptable alternative.

The term 'optical depth' is used to refer to the product of the gas concentration and the measurement pathlength. Optical depth is useful in discussing the measurement capabilities of an in-situ monitor. Figure 201.4 illustrates the concept. If a monitor's detection limit is 10 ppm on a four meter pathlength (double pass instrument on a two meter diameter stack) the minimum optical depth is 40 ppm-m ($4 \text{ m} \times 10 \text{ ppm} = 40 \text{ ppm-m}$). On a five meter stack (10 meters double pass pathlength) the minimum detection limit of this monitor will be 4 ppm ($40 \text{ ppm-m} / 10 \text{ m} = 4 \text{ ppm}$).

Another use of the optical depth concept is in the calculation of the required gas concentration in a flow-through gas calibration cell for calibrating in-situ monitors. If a 1000 ppm stack concentration on a 4 meter stack (double pass pathlength 8 m) is to be simulated, the concentration in the calibration cell must be 8000 ppm-m. The usual calibration cell is 1 cm (0.01 m). To get 8000 ppm-m in a 1 cm cell the concentration must be 800,000 ppm ($8000 \text{ ppm-m} / 0.01 \text{ m}$), or 80%. The required EPA protocol gases to conduct calibrations are not available in such high concentrations.

Single Pass
Double Pass

Optical Depth

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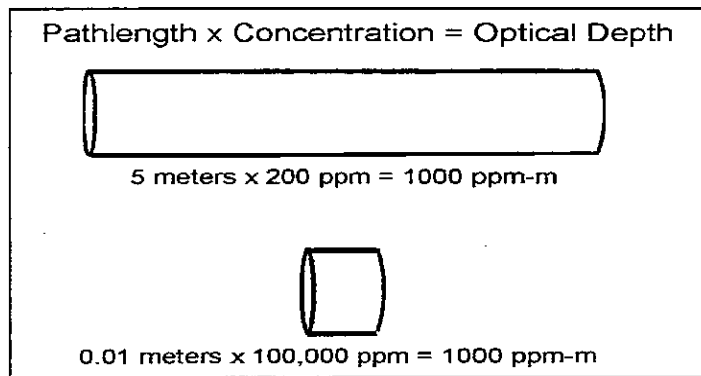


Figure 201.4 Optical Depth

201.2 EXTRACTIVE SYSTEMS

Source Level Dilution

Extractive monitors can be either source level, in which stack gases are conditioned and routed to the analyzers or dilution, in which the stack gases are diluted with clean dry air before routing them to the analyzers. The basic problem of extractive systems is that they are complex systems of equipment (Figure 201.5). They have many more individual pieces of equipment than the in-situ monitors. A distinct advantage to extractive systems, however, is that most of the equipment is usually at ground level, greatly facilitating maintenance.

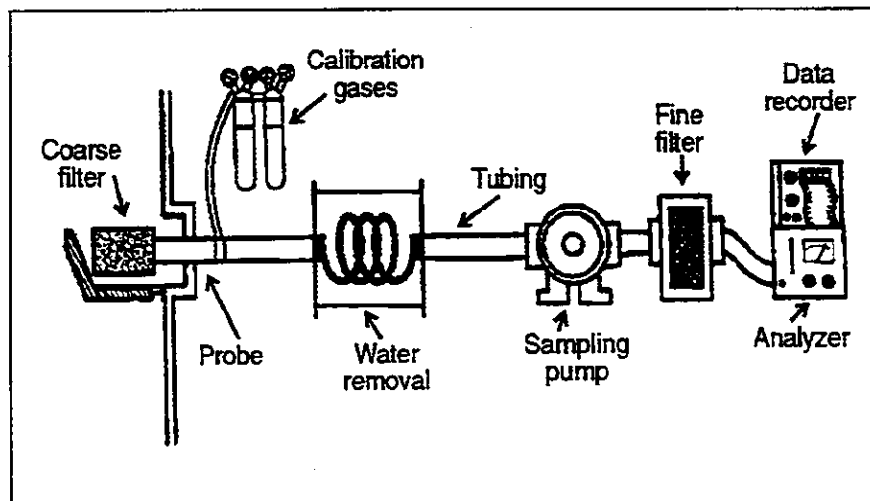


Figure 201.5 Basic Extractive CEM System³

201.2.1 Source Level Extractive CEMs

Most source level extractive CEM systems cool and condition the stack gases before routing them to the analyzer (cool-dry systems). Some systems, however, are designed to measure the hot, moisture laden gases directly using a heated analyzer (hot-wet systems). If there is ever any condensation in the hot-wet systems, the analyzers can be badly corroded.

In the cool-dry systems the gas is conditioned by reducing the temperature to ambient and the removing the moisture. The conditioning can be conducted either at the probe or at the analyzer shelter. Conditioning at the probe offers the advantage that the rest of the system does not need to be heated; however, daily maintenance of the conditioning system must be done at the probe level. Conditioning at the shelter is the more common practice. In this case the extracted stack gases must be maintained at elevated temperatures to prevent condensation of moisture in the sample line and subsequent absorption of water soluble gases until they reach the shelter. Maintaining heated gases requires heat traced sample lines.

To convert the concentration output of the monitor to the mass emission rate the total volume of stack gases, including water vapor, is needed. Hot-wet systems retain the moisture fraction; calculations are therefore simply a conversion from ppm to mass units with the inclusion of the wet stack flow rate (and correcting

$$C = \frac{\text{mg}}{\text{dscm}} = \frac{\text{ppm} \times \text{MW}}{22.414 \times (T_{\text{std}} / 273.15)} \left(\frac{T_{\text{std}}}{T_m} \right) \left(\frac{P_{\text{bar}}}{P_{\text{std}}} \right)$$

for stack temperature and pressure). The cool-dry systems, on the other hand require the moisture to be factored back into the stack gas volume.

$$C_w = C_d (1 - B_{ws})$$

Where: MW = pollutant molecular weight

C_w = wet gas concentration (i.e. at stack conditions)

C_d = dry gas concentration

B_{ws} = water vapor fraction

T_{std} = standard temperature

T_m = metered temperature

P_{bar} = measured (barometric) pressure

P_{std} = standard pressure

Cool-Dry
Systems
Hot-Wet
Systems

200 CEM THEORY AND DESIGN

The extractive systems that condition the gases allow greater flexibility in the choice of analyzers and are generally preferred when emission calculations are performed on a dry basis or when monitoring of several gases is required. These systems are also flexible enough to accommodate engineering changes when application problems arise or when components need to be modified or replaced to meet performance specifications.

The hot-wet systems can be advantageous for acid rain (40 CFR 75 or 'Part 75') sources in which the emissions must be reported as the mass emission rate. The preferred option of most of the Part 75 sources, however, is to use dilution probes, which reduce the moisture to a level below its dew point, and so remove the condensation problem without removing the water vapor.

201.2.2 Dilution Extractive CEMs

An increasingly common method of extractive sampling for monitoring is the use of dilution systems. The dilution systems can either use a dilution probe, which dilutes the sample as it is being taken, or the sample can be diluted outside of the stack, either at the probe level or at the ground in the CEM shelter. Most commonly, a dilution probe is used. These systems are commonly used on Part 75 acid rain sources since the water vapor content is retained, simplifying mass emission calculations.

Diluting the sample: 1) reduces the sample humidity, preventing water condensation and subsequent absorption of water soluble gases; 2) keeps sample volume low, often two orders of magnitude less sample must be drawn from the stack and filtered (e.g. 0.1 l/min vs 10 l/min), which reduces filter plugging since less sample must pass through the filter; and 3) minimizes corrosive properties of the sample.³ By reducing the humidity of the sample the condensation of water is prevented, allowing an unheated sample line to be used to bring the extracted sample down the CEM shelter at the ground. Additional advantages of the dilution probe include:

- Overall low maintenance and long life expectancy of the equipment, including filters.
- No need for valves and electricity at the probe location.
- The ability to use widely available conventional ambient air pollutant analyzers.

A major disadvantage of dilution systems is that any errors in the dilution ratio or sampling are greatly enlarged and can lead to a significant bias in the results. Also, dilution systems raise the detection limits of the analyzer. Therefore, if low detection limits are critical, a dilution system would not be appropriate.

201.3 REMOTE MONITORING SYSTEMS

Remote monitoring systems are ones that can detect emission concentrations from a distance without removing a sample of flue gases from the stack.^{6,7} Active remote systems project a beam of light into the emissions and detect the absorption or re-radiated light. A passive remote system senses the light radiating from the hot molecules emitted from the stack or the absorption of ambient light. EPA Reference Method 9A for monitoring opacity is an active remote monitoring method using a LIDAR (laser light detection and ranging) technique. One of the most common methods of monitoring emissions from stacks is a passive remote technique - visible emission evaluation determination of opacity (EPA Method 9).

Passive optical absorption radiometry (POAR) is a developing remote monitoring technique.⁸ The POAR was designed to operate from aircraft, but has also been used as a remote sensing monitor. It has been used to create maps of NO₂ and SO₂ over Moscow. The instrument is capable of measuring NO, NO₂, SO₂, CO₂, H₂S, and compounds containing benzene groups. As with many remote monitoring techniques, the POAR's field of vision is a column of air the diameter of the lens. This gives a path averaged measurement between the instruments and the ground (or other path termination).

Due to an inherent problem with defining the length of the measurement path in the plume, the accuracy of gas concentration data is poorer than that obtained by in-situ or extractive monitoring techniques. Relative accuracy (RA) better than 20 - 30% can rarely be achieved, whereas 10 to 15% RA is required of stack monitors.

Property-line open-path differential optical absorption spectroscopy (DOAS) is sometimes used to determine whether excess concentrations of emissions are crossing the property line of a source, potentially causing nuisance conditions. Potential nuisances or broad stroke estimates of emissions are the usual purview of remote monitoring systems (except VEE).

LIDAR

VEE

POAR

DOAS

200 CEM THEORY AND DESIGN

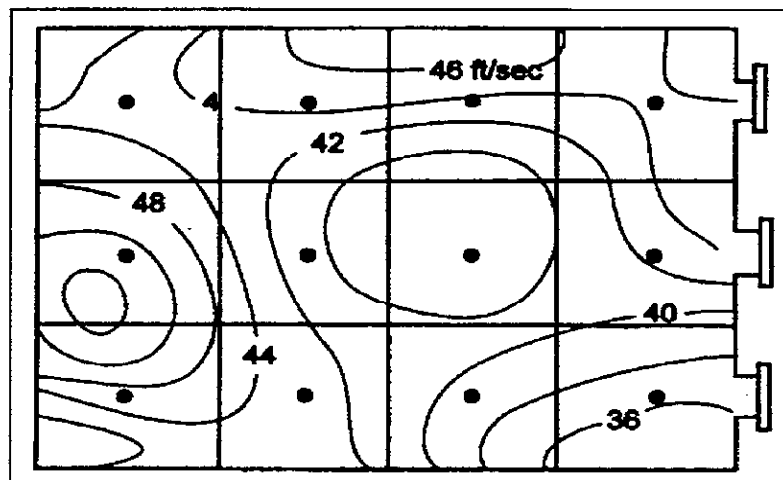


Figure 202.1 Velocity Stratification in Stack³

202 SYSTEM COMPONENTS

A continuous emission monitoring system is composed of three functional components or subsystems: the sample acquisition, the analyzer, and the data acquisition/controller subsystems.

202.1 SAMPLE ACQUISITION SUBSYSTEMS

The sample acquisition subsystem can vary in complexity from nonexistent in a path in-situ monitor to a complex assemblage of probe, umbilical, condenser, and conditioner in an extractive CEM system.

202.1.1 Sample Probes

Stack gases and particulate are often unevenly distributed across the stack (or stratified, Figure 202.1), therefore it is critical to locate the point at which the sample is withdrawn at a representative location. A simple probe can be made by inserting an open tube into the stack at a representative position.

In a stack where the flue gases are free of particulate such an open tube probe may be adequate. However, particulate free flue gases are rare. To minimize plugging by agglomerated particulate matter and condensation and to protect the sampling system a filter should be placed on the probe (Figure 202.2).

Probe filters remove the coarse particulate matter (10 - 50 μm) from the stack gases,^{1,3} the fine particulate is usually removed by a second filter immediately before the analyzer. The coarse filters are typically made of sintered stainless steel or porous ceramic materials. Occasionally a finer filter is used; however, fine filters plug easily and can cause a high pressure drop across the system.

To help minimize plugging of the coarse filter a baffle plate can be attached to the probe to divert particulate from the filter surface (Figure 202.2). This diverter is sometimes a simple v-bar deflector plate or cylindrical sheath around the filter. The particulate will be diverted by either of these configurations, but the gases will diffuse into the space between the deflector and the filter where it can enter the sampling system.

An advantage of the cylindrical sheath is that calibration gases can be injected into the space between the filter and the sheath to flood out stack gas and calibrate the entire monitoring system. It is important to inject the calibration gas outside the filter, if possible, since the particulate on the filter may bias the

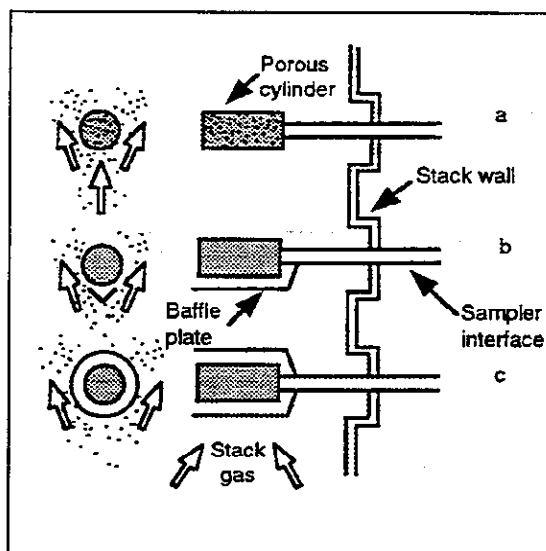


Figure 202.2 Probe Filters and Baffle Plates³

Filters

Baffle Plate

Calibration Gases

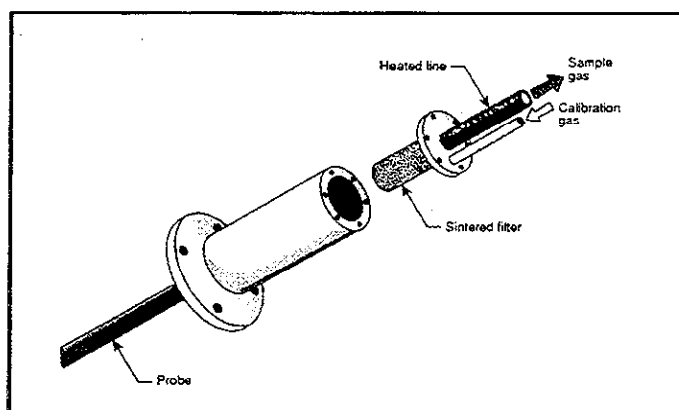


Figure 202.3 Internal Coarse Stack Filter³

Inertial Filter

sample. For example, SO_2 will interact with carbonate particulate and be removed from the gas stream as if by a stack gas dry scrubber.

A variation of the probe filter configuration is to use a simple tube probe and place the coarse filter in a housing at the base of the probe (Figure 202.3). This has the advantage that the probe does not have to be repositioned after each time the filter is changed. Also, the filter housing can conveniently be flooded with calibration gas.

A major problem associated with the previous filters is plugging. The inertial filter system^{1,3} can minimize this problem. The inertial filter is an internal filter design that can act as the primary filter, replacing the probe end filter, or as a secondary filter to further clean up particulate from the sampled gas stream. With an inertial filter as a secondary filter the probe end filter can have a coarser cut point (which would allow more particles through the filter) and lower pressure drop.

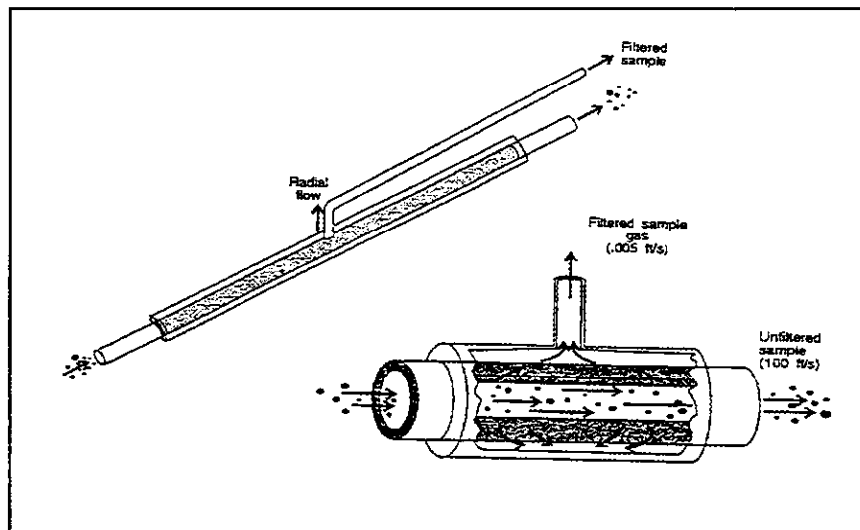


Figure 202.4 Inertial Filter³

The inertial filter can be incorporated into the probe assembly or into an external subsystem. In the inertial filter a pump pulls the flue gas sample through a cylindrical filter (Figure 202.4). The filter material is usually sintered stainless steel or porous ceramic, similar to the probe end filter discussed previously. As the gas moves through the tube a sample is drawn radially through the filter using another sampling pump. The large particles in the gas are swept through the tube

because of their inertia and the high flow (approximately 20 to 30 m/s) through the tube. The majority of the gas and entrained particles are exhausted back into the stack (Figure 202.5). Because of the high axial flow and low radial flow (approximately 0.0015 m/s) the large particles are unlikely to break the gas streamlines and enter the filter. The high axial flow also aids in sweeping any particles that do collect on the filter off the filter surface and back into the gas stream. It should be noted that particles (especially submicron size particles) do eventually collect on the filter and plug it.

Filter plugging is a problem with any extractive air monitoring system. To clean the filter a blowback system^{1,3} forces high pressure air or steam back through the probe and filter to dislodge the accumulated particulate. Depending on the particle characteristics and concentration, filters are blown back at intervals of once every 15 minutes to eight hours.

Blowback also should be restricted to periods no longer than necessary since during the blowback the monitoring system is off line. This period counts against the allowed monitor down time. The typical blowback period lasts for five to ten seconds. Care in the blowback cycle must be taken to prevent cooling of the probe to the extent that moisture or acid gases condense.

The probe itself may be something as simple as a tube placed in the stack at the appropriate position (generally with some sort of filter configuration), or it may be a complex dilution probe (Figure 202.6). Dilution extractive monitoring

Blowback

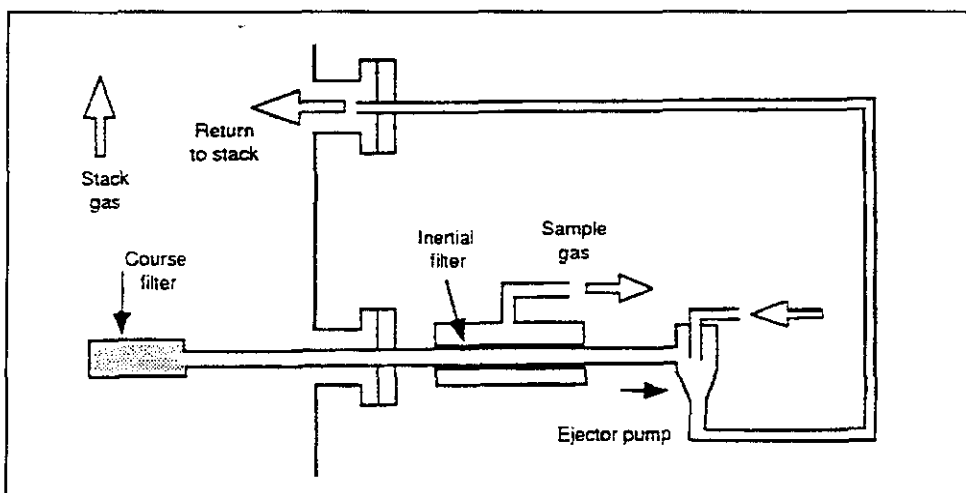


Figure 202.5 Inertial Filter Mounted Externally With Excess Flow Back into Stack³

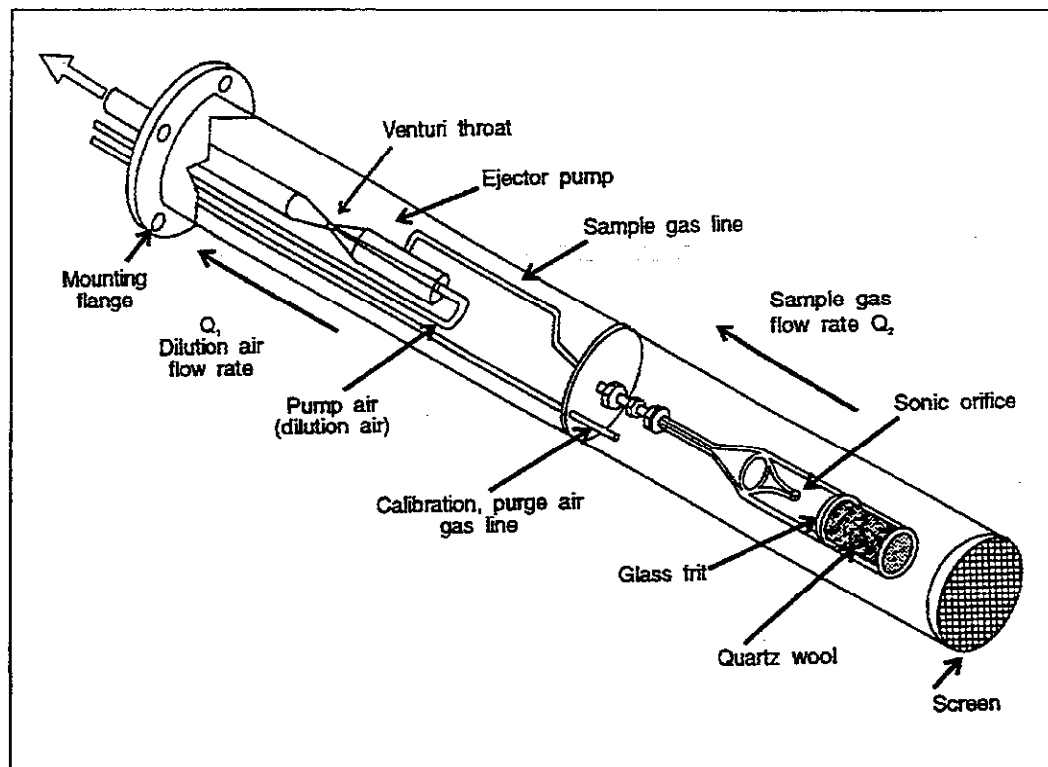


Figure 202.6 Dilution Probe³

systems^{1,3,9} can use regular extractive probes and accomplish the dilution function outside the stack or, more commonly, use a dilution probe.

A major problem associated with extractive monitoring systems is the need to collect, filter, and condition large volumes of stack gas. This problem can be mitigated by using a dilution system. A dilution system withdraws a sample of stack gas at a lower flow rate than source level extractive systems (e.g. 0.1 l/min vs 10 l/min). Because the flow rate is so low most particulate will tend to follow the streamlines of the bulk stack gas flow and not enter the probe. The dilution probe also dilutes the stack gas to such a degree that the dew point of the diluted sample will be below the lowest ambient temperature at the sampling location. This enables the CEM system to avoid the use of heat-traced sample lines to transport the sample to the analyzer shelter.

One of the most successful dilution probe designs uses a critical (or sonic) orifice coupled with an ejector pump designed into the probe body. The total volume of mixed air and stack gas from the ejector pump is 1 - 10 l/min,¹ sufficient to

Dilution Probes

supply the analyzers with diluted sample. The ejector pump pulls a strong vacuum on a glass critical orifice which is chosen to limit the flow of sample gas to flow rates from 50 to 500 ml/min. The accuracy of flow rates of the ejector pump and critical orifice are absolutely important to the accuracy of operation of a dilution sampling system. The condition for obtaining a critical flow for the critical orifice is that the ratio of the absolute pressure of the vacuum created by the ejector pump and the stack static pressure must be less than or equal to 0.53.¹⁰

Critical Orifice

$$R = \frac{Q_1 + Q_2}{Q_2}$$

The dilution ratio (R) is calculated as the ratio of the total sample flow rate to the stack gas flow rate.

Where Q_1 = dilution air flow rate (liters per minute)

Q_2 = stack gas flow rate (liters per minute)

Figure 202.7 illustrates a diluted sample. As can be seen, the proportion of moisture (and pollutant gas) are greatly reduced. Dilution ratios of 100 to 1 are typical, but ratios from 12:1 to 700:1 are sometimes seen. The dilution ratio desired is related to the analyzer being used and the concentration of pollutant in the stack. Often off-the-shelf ambient air analyzers are used, and the dilution ratio chosen to place the expected concentration of the diluted stack gas in an appropriate range of the analyzer.

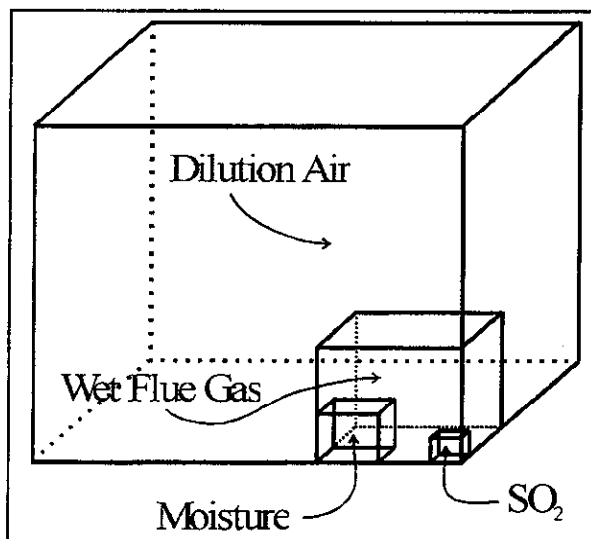


Figure 202.7 Diluted Gas Sample

Whenever the glass critical orifice is replaced the dilution probe must be recalibrated since slight variations in the orifices can translate into large variations in the concentrations in the diluted sample.

An advantage of the dilution probe is that it retains the water vapor in the gas sample, but removes the risk of moisture condensation. This is important for acid rain (Part 75) sources which must report emissions in

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mass emission rate terms. The dilution probe is, however, sensitive to changes in stack/ambient pressure and temperature and may not operate properly in stacks with high negative pressure (>250 mm H₂O vacuum). Also note that, since air is used to dilute the sample, an O₂ diluant gas analyzer cannot be used; the stack gas concentrations should be normalized to CO₂ content instead.

202.1.2 Sample Line

A sample line is used in an extractive monitoring system to transport the sample from the probe to other elements of the conditioning system or to the analyzer. In most cases the sample line must be heated to maintain the stack gases at a high enough temperature to prevent condensation of entrained moisture or other

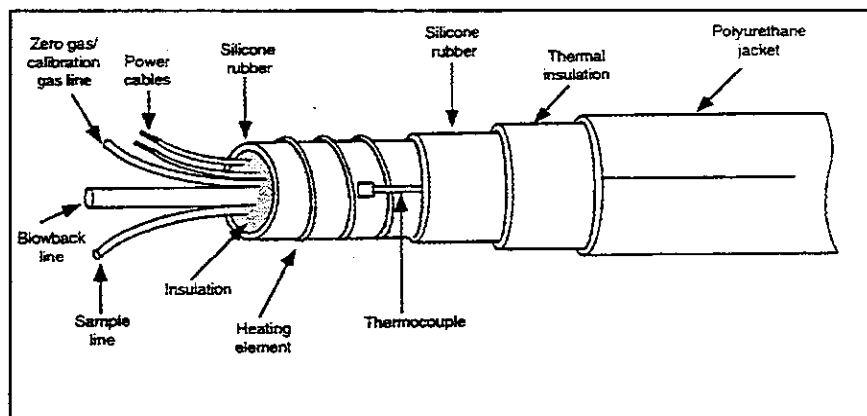


Figure 202.8 Umbilical Assembly³

Heated Sample Lines

modifications of the stack gases. This temperature is usually at least 120°C (250°F), or at a temperature similar to the stack temperature, to minimize changes in the sample during transport to the CEM shelter. If using a Teflon sample line, there is an upper limit of about 250°C. Above that temperature the Teflon tubing of the sample line may begin to soften. It is a good practice to heat even sample lines for diluted samples and samples that have been dried at the probe on the stack.

Should condensation occur in the sample line, the sample could be contaminated or acid gases and water soluble gases may be absorbed, biasing the sample. Also, an ice or particulate plug could form, or a pocket of condensed water or acid gas can lead to increased system corrosion. To prevent cool pockets in which condensation can occur, any joints in the sample line must also be heated and insulated.

The sample line is generally incorporated into a bundle, or umbilical, of sample lines, wires, etc. A typical umbilical assembly (Figure 202.8) contains the sample line itself, calibration gas lines, compressed air lines for blowback, and power lines for any powered equipment at the stack. These are then enclosed in a layer of insulation, wrapped with a heating element, and enclosed in a protective outer jacket. Thermocouples built into the umbilical assure that the temperature is being maintained. Since umbilicals can be very expensive and difficult to replace, extra wires and sample lines are often built in as the umbilical is made. If a break should occur in the sample line (or another line) one of the extra ones can be used without the downtime and expense of replacing the entire umbilical.

Umbilical Line

The sample line is usually made of PFA Teflon® for its chemical inertness. However, Teflon can soften at temperatures above 250°C. If high temperatures are required, stainless steel can be used.

In properly installed systems, heated sample lines are generally less than 75 meters (250 ft) in length. They are installed with a slope of at least 5° throughout their run to prevent any condensation that should occur from pooling. Care should be taken to prevent sags in the sample line.

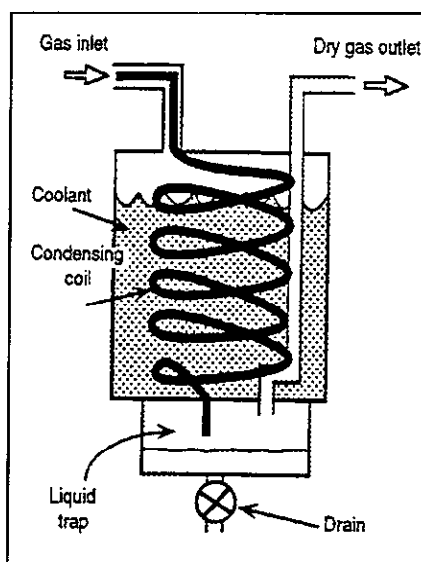
Length and Slope

202.1.3 Sample Conditioning

The primary conditioning required of stack gas before entering the sample pump or analyzer is to remove the moisture. In the process the gases are also cooled to around ambient temperature. If not removed, the moisture and condensable acid gases can condense and corrode the interior of sample pumps and analyzers. Condensation and permeation dryers are the most common drying systems in use on extractive monitoring systems.

Condensation Systems

A mechanically chilled condenser (Figure 202.9) is one of the typical moisture removal systems. In these systems a coil of glass, teflon, or stainless steel tubing is immersed in a bath of chilled water (sometimes with anti-



Moisture Removal

**Figure 202.9 Refrigerated
Condenser³**

freeze to prevent accidental freezing of the chiller bath) just above the freezing point (1° or 2°C). As the stack gases pass through the coil they are chilled below their dew point and the entrained water vapor condenses. The condensate water drains into a liquid trap and is pumped away for disposal. The dried gases then proceed to the pump or analyzer.

The traditional means of chilling the condenser is to use a mechanical refrigerator. A newer approach is to use a thermoelectric, or Peltier effect, chiller.¹

Thermoelectric chillers work on the Peltier effect with no moving parts (and no Freon required). The Peltier effect occurs when two dissimilar metals are joined in a loop (Figure 202.10) and a voltage is applied to produce a current. Because of the different electron distributions in the dissimilar materials, one junction will heat up; and at the other junction thermal energy will be absorbed.

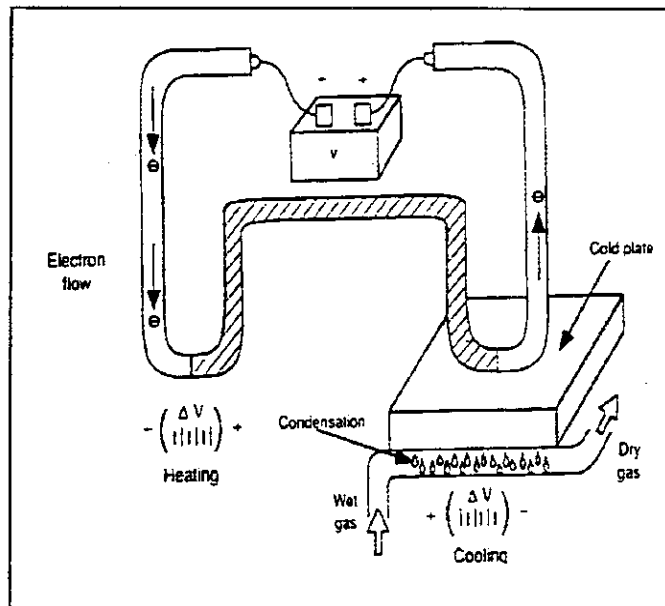


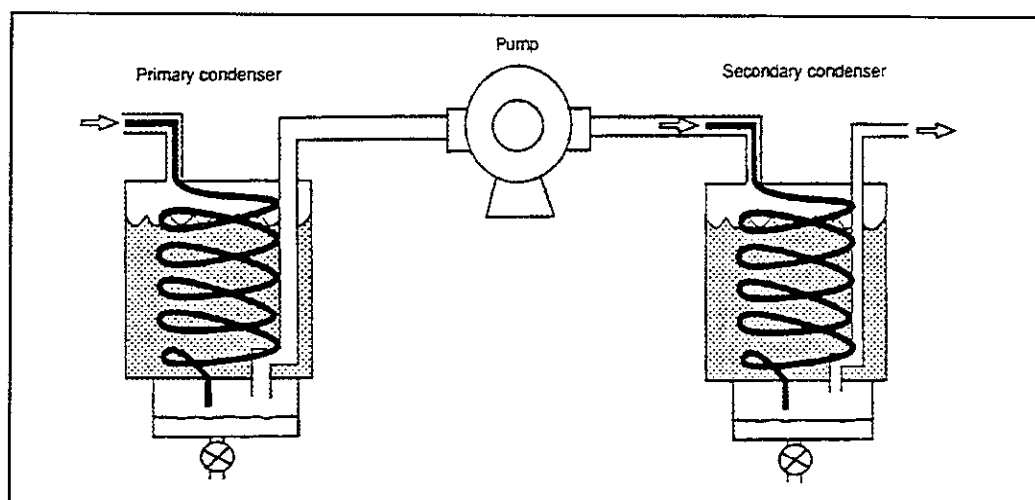
Figure 202.10 Peltier Effect Chiller³

An important aspect of the condenser type dryers is to keep contact between the gases to be analyzed and the condensed water to an absolute minimum; principally by minimizing the time in the condensor and the contact area. A number of the pollutant gases measured are soluble in water. This is especially a problem for HCl , NH_3 , and NO_2 , and to a significant, but lesser extent, SO_2 and NO .

Since a gas under pressure condenses more readily than when under a vacuum, a second condenser after the sample pump is sometimes added (Figure 202.11) to further dry the sample. This allows more thorough drying of the gas. It also allows each condenser to be operated at somewhat less stringent conditions, helping to minimize contact with the condensed water.

Peltier Effect Chiller

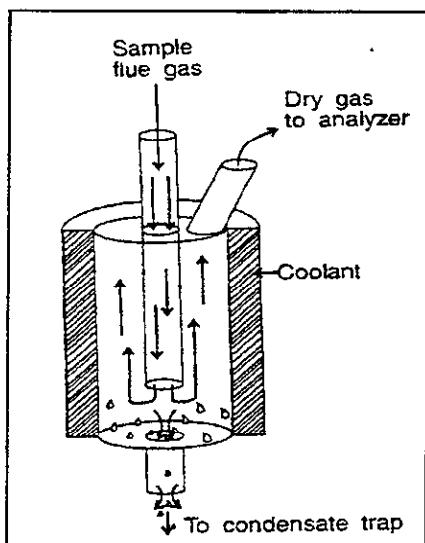
Pollutant Absorption

**Figure 202.11 Two Stage Condenser³**

Some systems employ a jet stream condenser (Figure 202.12) rather than the condensing tubing coil. The jet stream condenser cools the gas and then rapidly changes the direction of the gas to separate the condensing water droplets.

Most newer jet stream condensers use a Peltier chilled block of metal as the cooling source and to hold the impinger-like device.

Jet-Stream Condenser

**Figure 202.12 Jet
Stream Condenser³**

Permeation Dryers

Permeation dryers take advantage of the properties of ion exchange membranes to differentially transport specific molecules. In this case the membrane will pass water vapor molecules and retain the other constituents of stack gases¹¹. The most widely used material, Nafion®, is a copolymer of tetrafluoroethylene (Teflon®) and perfluoro-3,6-dioxo-4-methyl-7-octene-sulfonic acid.

Since it is a Teflon derivative, Nafion is highly resistant to chemical attack.

Nafion acts, not by membrane permeation, a relatively slow process, but by transfer of

water of hydration. The absorption of water of hydration is a rapid process, proceeding as a first order kinetic reaction. The exposed sulfonic acid group can absorb up to 13 water molecules for every sulfonic acid group in the polymer. Consequently, Nafion will absorb 22% by weight of water.

When a gas containing water vapor passes through Nafion tubing, the water is absorbed by the tubing walls and is passed from one copolymer molecule to another through the tubing structure (Figure 202.13). It evaporates into the surrounding air (pervaporation). This reaction is driven by the humidity gradient until an equilibrium is reached. A constant purge of dry air around the Nafion tubes is critically important to maintain the humidity gradient. A purge gas flow rate of twice the sample flow rate is generally sufficient to achieve full drying. The final dried stack gas exiting from the permeation dryer can be dried to a dew point as low as -45°C .

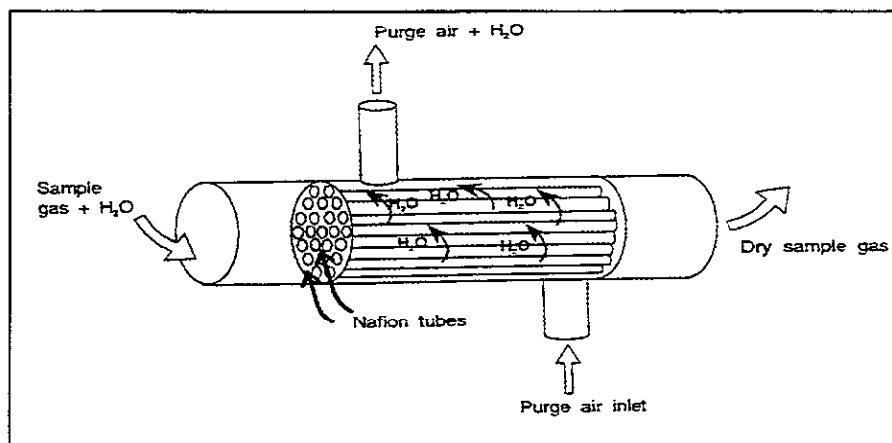


Figure 202.13 Permeation Dryer Assembly³

Pollutant Loss in Nafion

Although the Nafion is highly resistant to chemical attack and most substances are quantitatively retained in the stack gas, some polar organic substances and ammonia are absorbed by the tubing and lost along with the water vapor (Table 202.1). Permeation dryers should not be used when monitoring those substances that are not quantitatively retained in the sample gas stream.

202.1.4 Sampling Pumps

The sample pump is an integral part of an extractive monitoring system. The criteria for the pump are four-fold:³ the pump must be able to supply sufficient sample to the analyzers; it must be designed so no ambient air infiltrates into the

Table 202.1
Properties of Nafion Permeation
Drying Material¹¹

Totally Retained in Gas Stream	
Atmospheric Gases: N ₂ , O ₂ , H ₂ , Ar, He	Hydrocarbons: All Simple Hydrocarbons
Oxides: CO, CO ₂ , SO ₂ , SO ₃ , NO _x	Toxic Gases: HCN, COCl ₂ , NOCl
Halogens: Cl ₂ , F ₂ , HCl, HBr, Fluorocarbons	Other Organics: Aldehydes, THF, Cyanides, Esters
Sulfur: H ₂ S, COS, Mercaptans	Inorganic Acids: HNO ₃ , H ₂ SO ₄
Some Loss from Gas Stream	
Polar Organics: DMSO, Alcohols, Organic Acids, Ketones	Other: NH ₃ , Amines

sample stream; it must introduce no contaminants to the gas stream (i.e. from lubricating oils, seals, etc.); and it must be immune from attack by the stack gases. Most commonly, diaphragm or ejector pumps are used in CEM systems; on some systems both types of pumps are used.

The diaphragm pump operates by mechanically flexing a diaphragm, enlarging and contracting a pumping chamber (Figure 202.14). The diaphragm is in contact

Diaphragm Pump

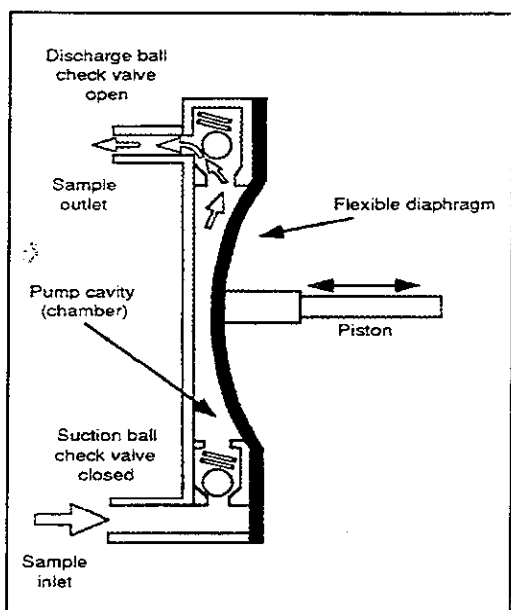


Figure 202.14 Diaphragm Pump Operation

with the stack gas, so it must be inert to its attack. The diaphragm is made of a flexible metal plate, Teflon, or some type of elastomeric compound. The reciprocating action moves the gas in rapid, short bursts. The keys to operation of diaphragm pumps are the ball valves on the entrance and exit of the pumping chamber. One ball valve is made to open on the inlet stroke (expansion of the chamber) while the other closes. On the exhaust stroke (contracting the chamber) the inlet ball valve closes and the exit valve opens. This sequence repeats on each stroke of the pump.

Diaphragm pumps are simple, rugged devices. However, after exposure to

the stack gases and constant flexing, the diaphragm will wear out. Fortunately, it is quite simple to repair. Replacement of the diaphragm should be done on a regular basis as part of preventive maintenance, rather than waiting for failure.

The flow from the pump can be regulated by throttling the inlet or outlet or by installing a bypass valve. Since installing a throttle valve can make the pump work against a high pressure, the life of the diaphragms will be reduced. It is generally better to control the flow with the bypass valve.

Ejector Pump

The ejector pump (also called an eductor or air aspirator pump) uses the Bernoulli effect to create a vacuum to draw a sample (Figure 202.15). In the Bernoulli effect a jet of air (usually high pressure plant operations compressed air) reduces the surrounding air pressure. This reduced pressure serves to draw the sample gas through the sample line. If the compressed air jet velocity is increased the vacuum is increased. The Bernoulli effect is also used in venturi flowmeters and jet carburetors.

The ejector pump is used in CEM systems to draw the primary sample in inertial filters (Figure 202.5) and in dilution probes (Figure 202.6). In inertial filter applications the quality of air used to draw the sample is of no consequence since the flow after the ejector pump, consisting of stack gases and pumping air, is dumped back into the stack for disposal. In the dilution probes, however, the quality of compressed air is of critical importance. The air to drive the pump becomes the dilution air and is part of the sample analyzed. Therefore, the dilution probe ejector pump compressed air must be dry and pollutant free.

202.1.5 Fine Filters

The coarse filter at the probe removes the majority of particulate and virtually all the larger particles. Before the sample is analyzed, however, any remaining particulate must be removed to prevent sample bias and damage to the analyzers. A fine filter (usually teflon or cellulose fiber) is placed immediately

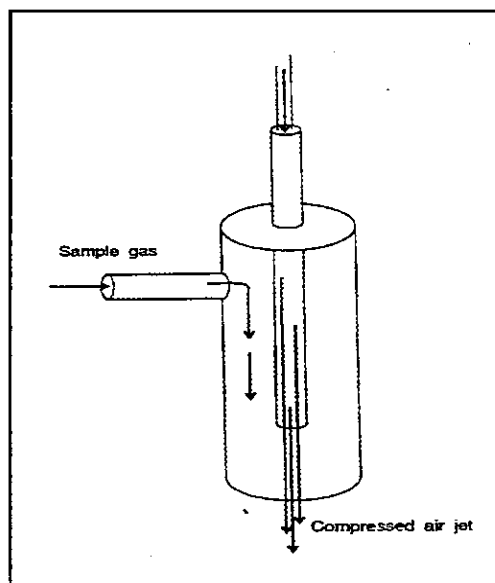


Figure 202.15 Ejector
Pump Operation³

before the sample enters the analyzer. This filter should be changed on a regular basis as part of routine maintenance of the CEM system.

202.2 ANALYZERS

The analytical techniques used in CEM systems, independent of whether the system is in-situ or extractive, encompass a wide range of chemical and physical measurement methods. These methods range from chemical reactions (e.g. chemiluminescent NO_x analyzers) and optical techniques (e.g. non-dispersive infrared (NDIR) absorption spectroscopy) to electroanalytical techniques (e.g. electrocatalytic oxygen analyzers) (Table 202.2).

Except for electroanalytical methods, the analyzers incorporate four primary components: 1) radiation sources, 2) spectral limiters, 3) optical components, and 4) detectors. Most electroanalytical methods use a heated catalyst bed to measure electrical flow induced by pollutant gas ionization or magnetic field effects, bypassing these listed components. The components in a specific monitor will differ depending on the analytical technique, but the following principles will generally apply.

Chemical,
Optical, Elec-
troanalytical
Techniques

Table 202.2
Analytical Techniques Used in CEM Systems^{1,3}

Extractive	In-Situ Gases	In-Situ Opacity
<u>Infrared Methods</u> Differential absorption Gas filter correlation Fourier transform infrared	<u>Point Analyzers</u> Ultraviolet Methods Second derivative spectroscopy Electroanalytical Methods Polarography Electrocatalysis	<u>Path Analyzers</u> Visible Light Scattering Absorption
<u>Ultraviolet Method</u> Differential absorption		
<u>Luminescence Methods</u> Fluorescence (SO ₂) Chemiluminescence (NO _x) Flame photometry (SO ₂)	<u>Path Analyzers</u> Infrared Methods Differential absorption Gas filter correlation	
<u>Electroanalytical Methods</u> Polarography Electrocatalysis (O ₂) Paramagnetism (O ₂) Conductivity	Ultraviolet Methods Differential absorption	

Light Range 200 nm to 6,000 nm

Radiation Sources

The radiation source in a monitor provides the light with which to perform the analysis. In most instruments the radiation source is a light emitting device; however in luminescence methods the radiation source is the excited sample itself. The light used in continuous monitoring instrumentation ranges from 200 nm in the ultraviolet to 6000 nm in the infrared. The infrared and ultraviolet light are outside the visual range of human sight, therefore the light is invisible to the human eye. However, since molecules of gases can 'see' and interact with this invisible light it is a useful analytical tool.

Infrared

Heated materials will emit light in the infrared region of the spectrum. Hence, most infrared sources are heated devices. Among these devices are Nernst globars (hollow zirconium and yttrium oxide rods), globars (silicon carbide rods), carbon rods, nichrome wire, and tungsten filament incandescent lamps. Other devices such as lasers and diode lasers are also used.

Visible

Visible light is usually generated by an incandescent lamp, filtered to exclude infrared and ultraviolet wavelengths. Visible sources are primarily used in opacity monitors where the peak spectral response is required to be in the visual range (500 to 600 nm). In addition, quartz halogen lamps and green LEDs are sometimes used as visible light sources.

Ultraviolet

Many of the ultraviolet sources use electronic stimulation and atomic transitions to generate fluorescence emissions in the ultraviolet range. The devices used in monitors include: hollow cathode gas discharge tubes, high-pressure hydrogen or deuterium discharge lamps, xenon arcs, and mercury discharge lamps.

Spectral Limiters

Filters

A spectral limiter restricts the wavelengths of light to only those of interest in the analysis process. If extraneous wavelengths are allowed in the monitor analyzing chamber, additional reactions or light absorptions could occur and interfere with a sensitive and clean signal from the instrument. The simplest spectral limiter would be a filter that allows only a narrow band of wavelengths to pass through it. Interference filters consisting of thin metallic films on glass are commonly used in the infrared region.

Diffraction Gratings

Diffraction gratings are commonly used in the ultraviolet region of the spectrum. The diffraction grating consists of a flat glass or aluminum plate, or a concave

surface that is ruled with very finely etched lines (approximately 750 lines per millimeter). Light from the grating will constructively or destructively interfere to separate light wavelengths.

Optical Components

Electro-optical continuous emission monitor system analyzers will inevitably contain a number of optical elements to direct and focus light. Lenses, slits, and diaphragms are used to focus light into the analysis chamber and onto the detector. Plain glass windows are used to separate the stack gases from the analytical components. The windows help keep the instruments from being impaired and are especially important for in-situ analyzers which are in direct contact with unmodified stack gases.

Half silvered mirrors are used to split a light beam, part going to the measurement analysis system and part to the reference. This allows a single radiation source to serve both functions and reduces noise and variability in the analyzer.

Motor driven choppers are employed to produce an oscillating light source. An oscillating light produces an oscillating electrical signal from the detector which can more readily be selected and filtered by the instrument electronics. This reduces the noise in the signal and improves the sensitivity of the instrument. In many in-situ path type opacity monitors the back side of the chopper has a mirror surface to produce a simulated zero signal between each measurement pulse.

Detectors

The detector is a device to capture and translate the effect created by the pollutant gas on the analytical system. An electrical signal from the detector is further amplified, conditioned and stored by the electronics of the monitor instrumentation. The type of detector used depends on the type of monitor and the energy of light it is using.

Infrared light is fairly weak in the energy it carries, therefore, maximizing the sensitivity and discrimination of the detector is important. Infrared instruments typically use thermal detectors.¹ Traditionally these detectors sense the pressure in a closed detector cell due to absorption and heating by the analytical light. Newer, solid-state devices such as mercury cadmium telluride, lead sulfide, or arsenic triselenide light sensitive cells are increasingly being used. The sensitivity of the solid-state devices is increased by chilling with a thermoelectric chiller.

Focusing

Windows

Mirrors

Choppers

**Thermal
Detectors**

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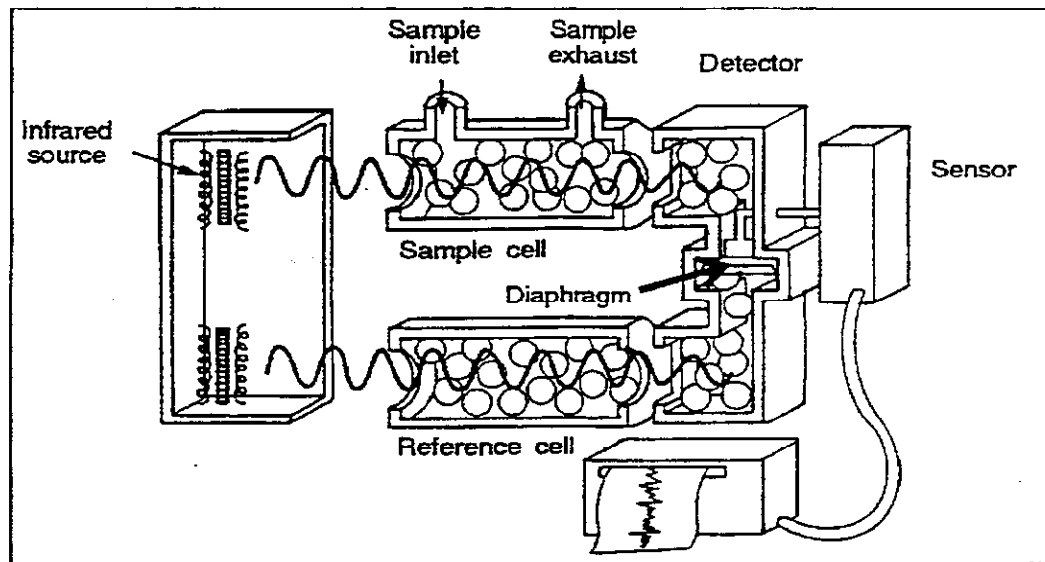


Figure 202.16 Pneumatic Detector³

Pneumatic Detector

In a pneumatic detector (Figure 202.16) a thin metal diaphragm separates two gas-tight chambers filled with a high concentration of the gas being measured. The gas molecules absorb the IR radiation causing the gas to heat up. Following gas law principles, the heated gas expands, causing a higher pressure in the detector cells. The measurement chamber of the detector will be heated less than the reference chamber, in direct proportion to the amount of IR radiation attenuated by the sample gas stream. The difference in pressure will cause the metal diaphragm to flex. In most designs a variable capacitance is measured between the flexing diaphragm and a charged, fixed metal plate. The distance between the plates is inversely proportional to the capacitance and directly proportional to the voltage.

Analyzers generally employ a rotating chopper wheel to produce a fluctuating light source. The light fluctuations result in oscillating pressures and, hence, oscillating voltage signals from the detector. The pneumatic detector operates somewhat like a microphone (and is sometimes referred to as a microphone detector).

The most significant problem with a pneumatic detector is that it is sensitive to vibration, which also flexes the diaphragm, producing a noisy signal. The device, therefore, must be isolated from vibrations due to plant processes etc. and is difficult to use in an on-stack installation.

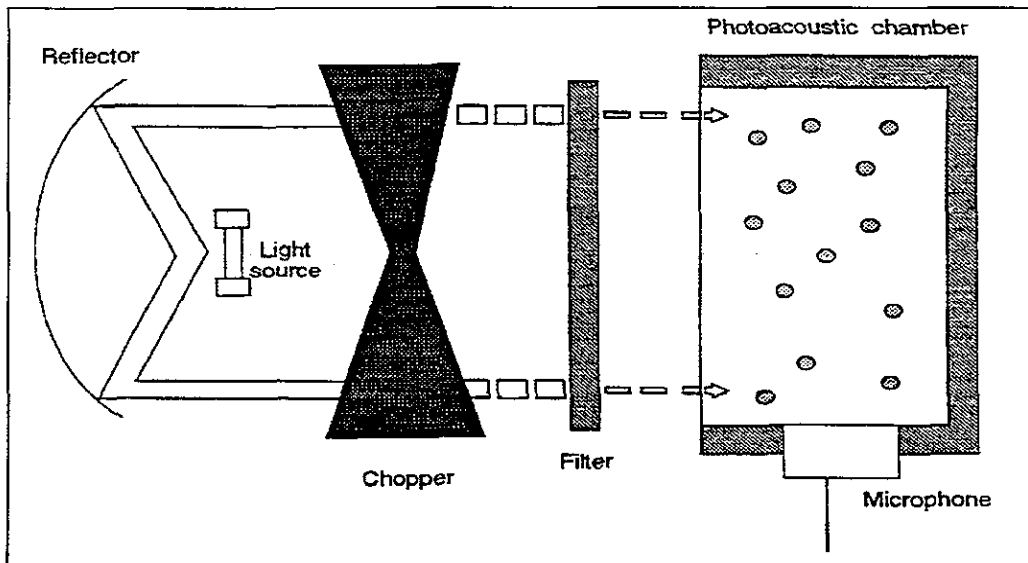


Figure 202.17 Photoacoustic Detector

A variation of the pneumatic detector which overcomes much of the vibration sensitivity uses a thin heated grid instead of a flexible metal diaphragm. The grid is cooled by the detector chamber gases moving between chambers to equalize the pressures. The grid functions in a manner like the heated wire flue gas velocity monitoring instruments.

Another variation of the pneumatic detector is the photoacoustic chamber detector (Figure 202.17). This detector uses a single chamber and measures the fluctuating chamber pressure with a condenser microphone. For the microphone of the photoacoustic chamber to work, the instrument must modulate the light beam at 20 Hz to 20 kHz. Again, these detectors are sensitive to vibration (especially in the frequency range picked up by the microphone). With a sensitive microphone a photoacoustic detector can measure pollutant concentrations to parts per billion levels.

Since EPA Method 9 for visible emissions is the most commonly used monitoring procedure, the most commonly used detector in the visual range is the human eye.

For ultraviolet and visible monitors phototubes, photomultiplier tubes, and photovoltaic cell detectors are commonly used. Each of these devices produces an electrical voltage proportional to the amount of light that falls on the detector.

**Photoacoustic
Chamber**

Human Eye

Phototubes

Photodiode Array

Solid-state detectors are also making inroads into monitoring instruments operating in the UV and visible light ranges^{1,3,12}. The prevalent solid-state device in use is the photodiode array detector (Figure 202.18). The photodiode array detector is a semiconductor array of 128 to over 4000 small diode elements. When light strikes the n-type semiconductor substrate an electron is freed which discharges a local diode element. The voltage needed to recharge the array is a measure of the light intensity.

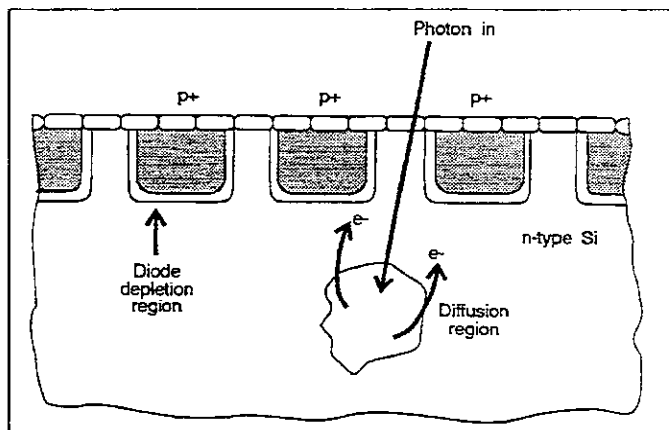


Figure 202.18 Photodiode Array Detector³

By using a photodiode array detector with a diffraction grating, an entire spectrum can be obtained in a few seconds. In this way, these detectors are especially good for measuring multiple wavelengths or in instruments capable of monitoring multiple pollutant gases.

Electrical Signal

Electroanalytical instruments typically directly generate an electrical signal. That signal is then fed into the electronics and data storage functions of the instrument.

202.3 DATA ACQUISITION AND MANIPULATION SUBSYSTEMS

The electronics of a CEM serve as an interface between the measurement systems and the end purpose of the data. They acquire and translate the raw signals from the detector and store it in a manner in which the emissions status of the unit being monitored can be determined. The systems also must be able to convert the data into the proper reporting units and averaging times and be able to present the data in report format.

With all that DAS systems are called on to do, it is an obvious place for increasing computerization. Many air pollution control districts in California now are requiring all monitoring systems to be accessible through computer modem

connections. These sources can then be called up on line to determine the immediate emission status.

203 VELOCITY MONITORS

Continuous Emission Rate (or velocity) Monitoring Systems (CERMS) are required whenever the emissions from a facility are required to be reported as a mass emission rate. An important program requiring mass emission rate reporting, hence velocity monitoring, is the Part 75 acid rain monitoring program.

As can be seen from the following equations, the velocity is important in calculating the mass emission rate:¹

$$\text{pmr}_s = C_s Q_s$$

$$Q_s = A_s v_s$$

Where: pmr_s = pollutant mass rate (kilograms per unit time, pounds per unit time, tons per year, etc.)

C_s = pollutant concentration (grams per cubic meter, pounds per cubic foot, etc)

Q_s = stack gas flow rate (cubic meters per second, cubic feet minute, etc.)

A_s = stack or duct area (square meters or square feet)

v_s = stack gas velocity (meters per unit time or feet per unit time)

In these equations it is also important to note that all the parameters are in stack condition bases.

A number of methods to monitor flue gas velocity have been developed (Table 203.1). Parametric methods, such as calculating from f-factors or fan horsepower have been used, however, these methods generally do not satisfy the precision and accuracy needed.

Monitors to measure flue gas velocity are inherently in-situ monitors, since

Table 203.1 Velocity Monitoring Techniques

Technique	Instrumentation or Sensor
Differential pressure sensing	Pitot tube Annubar
Thermal sensing	Heated sensor
Acoustic velocimetry	Ultrasonic transducers

Mass
Emission
Rate

dynamic measurements are needed. Some techniques are point in-situ monitors which measure the velocity at a point (or multiple points) in the stack. Other techniques, such as ultrasonic transducers, are path in-situ monitors.

As with all in-situ methods, velocity sensors are subject to particulate agglomeration and corrosion by the stack gases. A preventive maintenance program is important to prevent system degradation failure. Blowback techniques can be used on some systems to remove particulate accumulations; others must be removed from the stack to be physically cleaned.

203.1 DIFFERENTIAL PRESSURE SENSING

Differential pressure sensing velocity monitors measure the pressure effects of moving gases. To obtain the volumetric flow rate in the stack the temperature, pressure, and the molecular weight of the gases is also required.^{1,3} These values must either be assumed or measured. To measure the stack temperature and pressure are simple operations of incorporating additional sensors; to measure molecular weight is another matter. Usually molecular weight is assumed to be the molecular weight measurements during the latest source test. Molecular weight calculations are not overly sensitive to the exact stack gas composition, a good approximation based on the latest data will generally suffice.

203.1.1 Pitot Tubes

The simplest means of monitoring stack gas velocity is to affix a source test pitot tube at a representative point in the stack. A pitot tube consists of two pressure measurements. The first, the 'impact' or 'stagnation' pressure, is measured by an open tube oriented directly into the stack gas flow. The second measurement is the static or total pressure in the

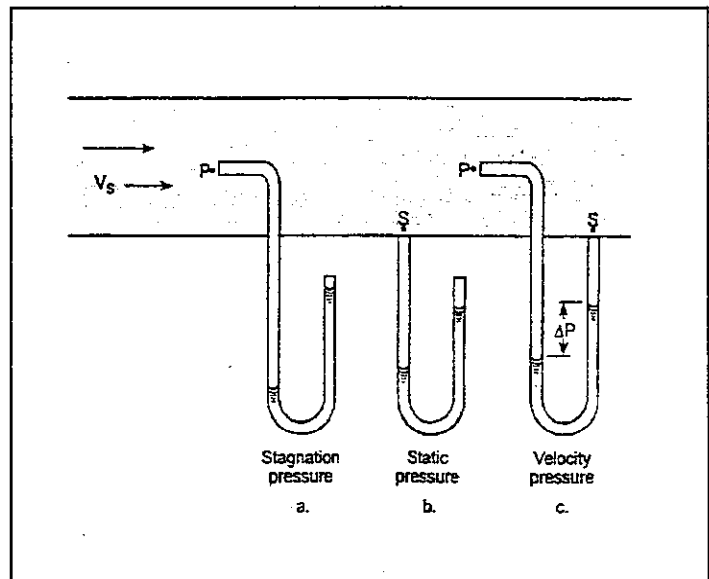
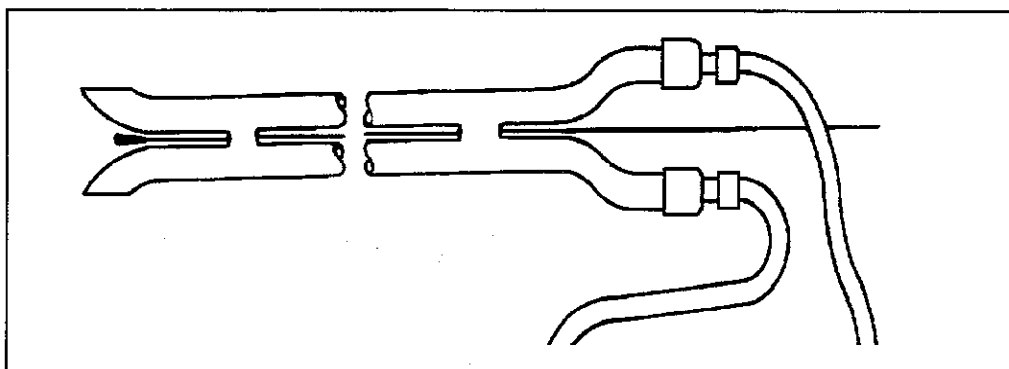


Figure 203.1 Measuring Velocity Pressure¹³

Stagnation
Pressure

Static
Pressure

Figure 203.2 S-Type Pitot Tube⁴

stack. The difference between these two measurements is the velocity pressure (Figure 203.1). The velocity pressure, Δp , is related to the velocity by the following relationship:

$$v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{P_s MW_s}}$$

Where v_s = velocity of the stack gas

K_p = dimensional constant

C_p = pitot tube calibration coefficient

T_s = stack absolute temperature

P_s = stack absolute pressure

MW_s = molecular weight of the stack gas (wet basis)

The most commonly used pitot tube is the type-S (Strausscheibe) pitot tube (Figure 203.2) specified in EPA Reference Method 2. The Reference Method⁴ contains a detailed description of the construction and calibration of this device.

Since a pitot tube measures the velocity at a single point, it is very important that the measurement point be representative of the entire flow in the stack. Multiple pitot tubes spaced on a traverse of the stack can be used to get an average value across the stack. A simpler averaging technique is to use an annubar (Section 203.1.2).

203.1.2 Annubar

An annubar (Figure 203.3) is similar to a modified pitot tube having four or more sensing ports. The net effect of having several sensing ports is to average the

**Velocity
Pressure**

velocity using the flow rate at the locations of the ports. The ports on the annubar are generally laid out in the positions specified by Reference Method 1. As with the pitot tube, an annubar should be equipped with a blowback particulate removal system.

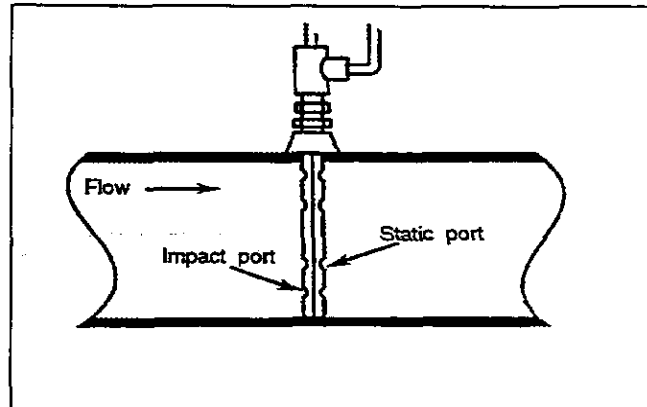


Figure 203.3 Annubar³

203.2 THERMAL SENSING SYSTEMS

Heat Transfer

Thermal sensing velocity measurement devices (Figure 203.4) transfer heat from a heated body to the flowing gases¹⁴. The amount of heating required to maintain the sensor at a constant temperature is proportional to the flow rate. In addition to the heated sensor, a stack gas temperature probe is required to compensate for changes in stack temperature.

Mass Flow Rate

Thermal sensors differ from differential pressure-type devices in that the thermal sensors measure the mass flow rate (kg/hr, lb/hr, etc.) of the stack gases and the pressure devices measure the volumetric flow rate. To calculate the velocity (m/s, ft/s) or volumetric flow rate (m³/hr, ft³/hr), knowledge of the gas density (g/m³, lb/ft³) is required. The cooling rate of the heated probe is dependent on the thermal conductivity of the gases which, in turn, is dependent on the gas viscosity and specific heat. The heat loss can be expressed as a proportionality:¹

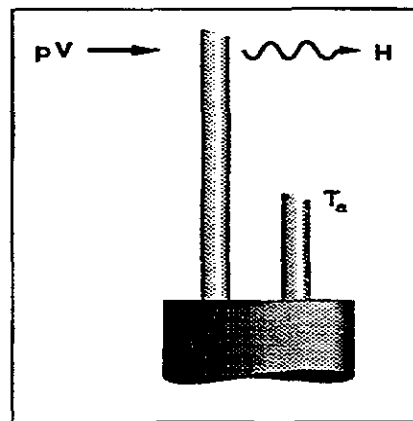


Figure 203.4 Thermal Velocity Sensor³

$$\{\text{heat loss}\} \propto k \propto \eta c \propto \rho v_s c$$

$$\{\text{signal}\} \propto \{\text{heat loss}\} \propto \rho v_s A_s$$

Where: k = thermal conductivity
 η = viscosity
 c = specific heat
 ρ = gas density
 v_s = gas velocity
 A_s = stack area

Thermal sensors can easily be arrayed in several points through the stack diameter

(usually on Reference Method 1 locations) to give independent measurements at each point. These measurements can be averaged or used to monitor stratification of the stack gases.

203.3 Acoustic Velocimetry

Acoustic velocimetry (Figure 203.5) uses ultrasonic pulses to measure the velocity of the stack gases¹⁴. A sound pulse traveling with the flow in a stack will be accelerated by the gas and particulate flow; conversely, a pulse traveling against the flow will be slowed. This Doppler shift is similar to listening to a train approach and pass - the whistle will change in pitch in proportion to the speed of the train.

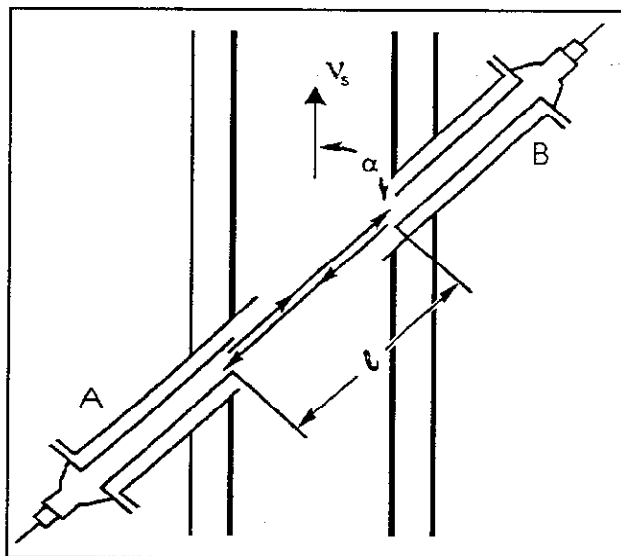


Figure 203.5 Acoustic Velocity Measurement³

In this method of velocity monitoring two transceivers are located on opposite sides of the stack, typically at an angle of 45° . Each transceiver generates an ultrasonic pulse in the range of 50 kHz toward the other transceiver. The difference in transit time of the two pulses is used to calculate the velocity.

$$v_A = \frac{l}{t_A} = c + v_s \cos \alpha$$

$$v_B = \frac{l}{t_B} = c - v_s \cos \alpha$$

Where v_A = speed from A to B

v_B = speed from B to A

v_s = stack gas velocity

l = path length from A to B

t_A = forward transit time from A to B

t_B = reverse transit time from B to A

c = speed of sound

α = angle between stack and path l

Doppler Shift

Velocity

By subtracting the v_B from v_A the stack gas velocity is obtained. It is interesting to note that the expression for stack velocity is independent of the speed of sound, c . The expression is also independent of other gas properties such as density, pressure, or temperature.

$$v_s = \frac{1}{2\cos\alpha} \left(\frac{1}{t_A} - \frac{1}{t_B} \right)$$

If the forward and reverse velocities are added ($v_A + v_B$) the speed of sound, c , can be obtained:

$$c = \frac{l}{2} \left(\frac{t_A + t_B}{t_A t_B} \right)$$

Temperature

Since the speed of sound is temperature dependent by the expression:

$$c = KT^{1/2}$$

(where K is a constant), the stack gas temperature can be derived as:

$$T = \left(\frac{c}{K} \right)^2$$

In this case c is dependent on the stack gas composition and the specific heats of the gases. Correction factors can be applied with reasonable success.

Internal Zero
Check

A feature unique to the technique is that it provides a means of internal checks. An internal zero can be obtained by electronically substituting the signal going with the flow for the one going against the flow. This should result in $t_A = t_B$ and $v_s = 0$. An upscale check can be obtained by introducing a known delay in the tone pulses and monitoring the delay.

Upscale
Check

Because the instrument is cross stack and not directly in the stack flow, it is not subject to corrosion and particulate fouling so long as a purge air is blown through the transceivers.

204 PHOTOANALYTICAL MONITORS

Most CEM systems use photoanalytical, i.e. optical, techniques to measure pollutant concentrations. Optical monitoring uses the light absorption properties of a gas to determine its concentration.

Stack monitoring systems are either active or passive systems. The active systems transmit a light beam through the sample and measure the light absorption. In contrast, the passive systems detect light emitted by the sample, usually involving a gas phase chemical or physical reaction.

204.1 CHARACTERISTICS OF LIGHT

Light can be characterized as waves of oscillating electric and magnetic fields. However, in interactions with matter, light behaves as if it were composed of discrete packets of energy, called photons. The length of the oscillations of the electromagnetic waves of light is its wavelength (λ) (Figure 204.1). The units for wavelength are most commonly nanometers (nm, 10^{-9} m), although angstroms (\AA , 10^{-10} m) and micrometers (μm , 10^{-6} m) are also used. The number of oscillation cycles occurring per second is termed the frequency (ν) of the light in hertz (cycles/second).

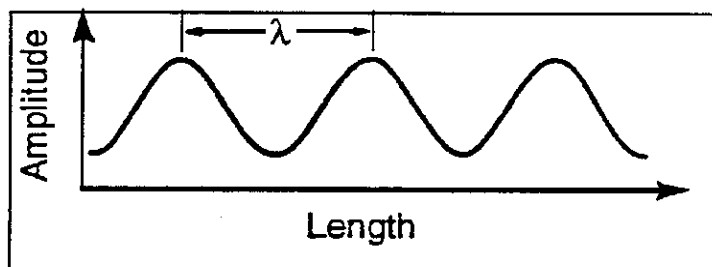


Figure 204.1 Wavelength of light

204.1.1 Basic Theory of Light

The following describes the relationship between the wavelength and frequency (c = speed of light; 3.0×10^8 m/s):

$$\nu = \frac{c}{\lambda}$$

The electromagnetic spectrum can be divided into several regions (Figure 204.2). Light with an intermediate wavelength (400 to 700 nm) is visible to the human eye; light with a shorter wavelength (less than 400 nm) is termed ultraviolet; and light of longer wavelength (greater than 700 nm) is termed infrared. In air pollution monitoring the wavelengths of light used range from approximately 200 nm in the infrared region of the spectrum to 6000 nm in the ultraviolet region.

The wavelength (or frequency) of light is dependent on the amount of energy carried by each photon. Light in the ultraviolet region has a shorter wavelength and higher energy while light in the infrared region has a longer wavelength and lower energy (E).

Wavelength (λ)

Frequency (ν)

Visible,
Ultraviolet,
Infrared

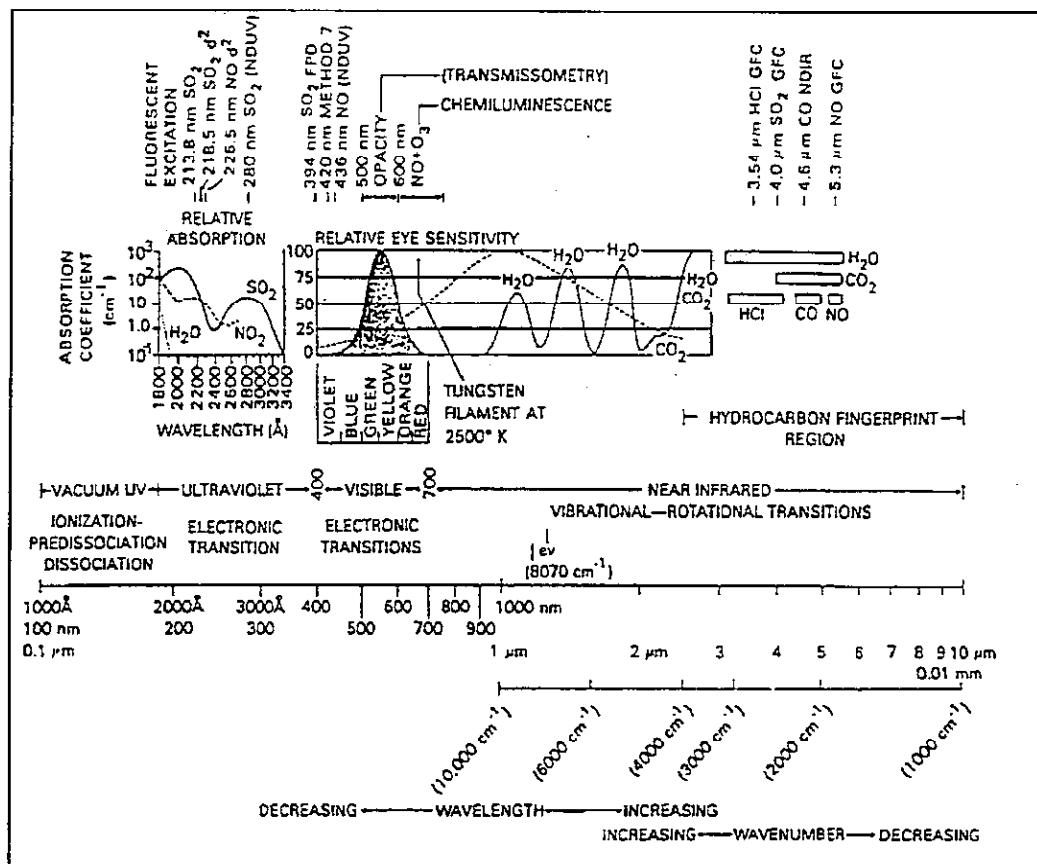


Figure 204.2 Spectrum of Light³

$$E = h\nu = \frac{hc}{\lambda}$$

Where h = Plank's constant, 6.63×10^{-27} erg-s

It should be noted that there is a significant difference between the energy of light and its intensity. The energy of light refers to the wavelength or frequency of each photon, i.e. how much energy is carried by the photon; the intensity of the light refers to the number of photons.

204.1.2 Absorption of Light by Gases

Molecules are made up of atoms and molecular electrons that are arranged in specific patterns which can undergo specific motions (vibrational or rotational).

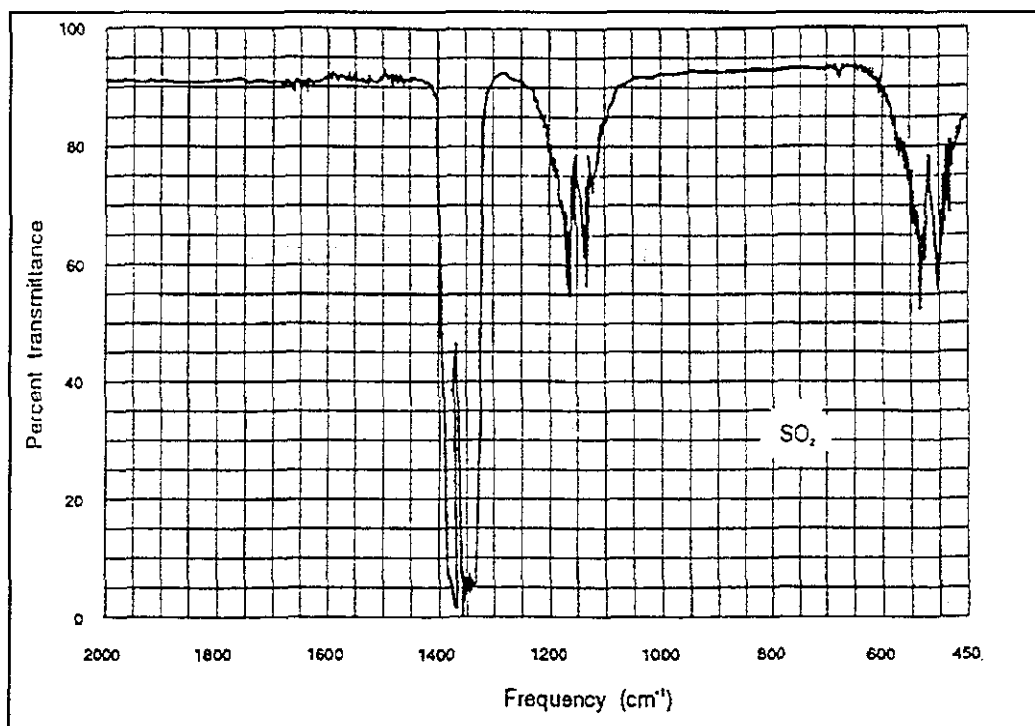


Figure 204.3 Infrared Transmission Spectrum of SO_2 . An Absorption Spectrum Would be the Inverse of This Figure³

If light of a given energy resonates with one of these allowed motions it will have a high probability of being absorbed by that molecule. Light that does not resonate will not be absorbed. The photon will be absorbed in total if it resonates, or passed in total if it doesn't. It will never be partially absorbed. Thus, light from a continuous spectrum, after passing through a gas, will have bands (or absorption lines) where the resonant photons have been absorbed (Figure 204.3). This process provides a means by which pollutant gases can be analyzed - by using a light consisting only of photons that will be absorbed. The concentration is directly related to the degree to which light is absorbed.

Absorption Bands

Beer-Lambert Law

When studying the absorption of light by gases, the Beer-Lambert law can be used to relate the amount of light absorbed to the concentration of the pollutant gas. The Beer-Lambert law¹⁰ states that the ratio of the exit (I) and initial (I_0) light intensities, i.e. transmittance of light (T), through a pollutant gas is decreased exponentially as the product of the molecular absorption coefficient

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(α), the concentration of the pollutant (c), and the pathlength through the analysis chamber (l). The absorption coefficient is dependent on the wavelength of light used for the analysis and the properties of the molecules detected.

This principle can be used to detect and monitor the emission air pollutants. A light of the proper wavelength, selected to interact with the pollutant of interest and have no effects with any other gases in the air, can be passed through the

$$T = \frac{I}{I_0} = e^{-\alpha c l}$$

stack or a sample cell. The intensity of the light will be attenuated by the pollutant. This attenuated measurement light beam then can be compared to the original intensity of the light and the concentration of the pollutant calculated from the ratio of the two light intensity measurements (I/I_0) by the Beer-Lambert law.

The Beer-Lambert equation can be rearranged to calculate the pollutant concentration:

$$c = \frac{-\ln\left(\frac{I}{I_0}\right)}{\alpha l}$$

Calibrations

A calibration of the instrument is important to compensate for the configuration and construction of the analyzer and the molecular absorption coefficient of the pollutant gas. Usually an empirical calibration using several concentrations of the pollutant gas of interest is conducted rather than calculations based on

theoretical values. A logarithmic plot (Figure 204.4) of the transmittance ($\ln(1/T)$) gives a straight line against which the stack gases can be compared and the concentration of pollutant gases calculated.

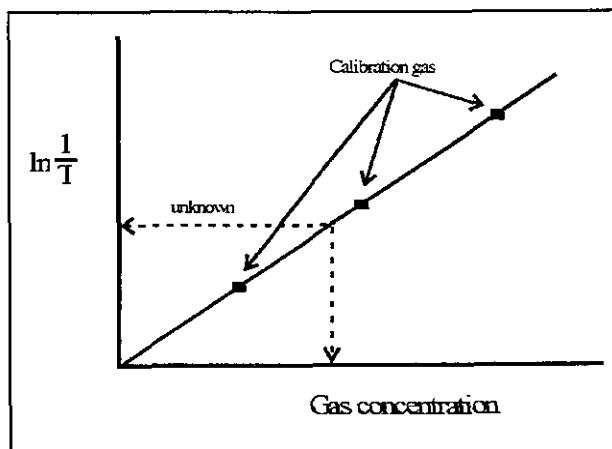


Figure 204.4 Calibration of an Analyzer

204.1.3 Absorption and Scattering of Light By Particles

In addition to interactions with gas molecules, light will interact with particulate matter.¹⁰ Particulate matter, including solid and liquid aerosols and droplets, will absorb and scatter light. The mechanisms of scattering are dependent on the size of the particle and the wavelength of light.

There are three basic types of scattering that occur. If the particle is much smaller than the wavelength of light, the particle-light interaction will be described by Rayleigh scattering. When the particle diameter is comparable to the wavelength of light, Mie scattering principles will apply. Thirdly, if the particulate is much larger than the wavelength of light, geometric optics explain the interaction. Stack flue gases typically contain particles from 0.1 to 10 μm or greater, therefore, all three interaction types can occur.

Rayleigh Scattering

Particles smaller than 0.1 μm will scatter visible light by Rayleigh scattering principles. In Rayleigh scattering the instantaneous electromagnetic field of the incident light is uniform over the entire particle. This creates an oscillating dipole interaction with the electrons within the molecules of the particle by accelerating them. The oscillating dipole reradiates the electromagnetic radiation in all directions. The result of this phenomenon is that light is very effectively scattered out of the light beam.

$$d_p < 0.1 \mu\text{m}$$

Mie Scattering

When the diameter of the particle is on the order of the wavelength of light the molecular electrons no longer see a uniform electromagnetic field from the light. The electromagnetic field will vary in direction and intensity throughout the particle, causing the electrons to accelerate and scatter in different directions. The scattering light can constructively and destructively interfere giving a complex scattering pattern. A bright hazy appearance of the atmosphere is a result of forward Mie scattering.

$$d_p \sim \text{Wave-} \\ \text{length of} \\ \text{Light}$$

Geometric Optics

For large particles, where the size of the particle is greater than 20 times the wavelength of the incident light, the interaction between light and the particle is

$$d_p \sim 20 \text{ Times} \\ \text{Wavelength} \\ \text{of Light}$$

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described by geometrical optics. This interaction is described by individual rays of light that are reflected, refracted, diffracted, and absorbed by the particle.

Bouguer's Law

Particle scattering and absorption effects can be treated in a manner similar to the Beer-Lambert law for gases. Bouguer's law states that transmittance is decreased exponentially.

$$T = \frac{I}{I_0} = e^{-naQl}$$

Where n = number concentration of the particles

a = projected area of the particles

Q = particle extinction coefficient

l = pathlength

The particle extinction factor (Q) is dependent on the wavelength of light and particle size and expresses how the particle will absorb and scatter light (as discussed above).

204.1.4 Opacity and Transmittance

The transmission of light through a flue gas that contains particulate matter will be reduced by scattering and absorption processes. The scattering and absorption gives rise to the opacity, or opaqueness, of the emission plume. A plume that has an opacity of 100% will be completely impervious to the transmission of light, i.e. if the plume is 100% opaque the transmittance is 0% and if a plume is transparent it will have an opacity of 0% and transmittance of 100%. In stack emission monitoring an opacity monitor measures the percent reduction of light transmittance through the plume.

$$T(\%) = 100 - \text{Opacity}(\%)$$

Bouguer's law is somewhat difficult to use for stack emission calculations, therefore, another expression, optical density (D), is frequently used in opacity monitoring¹⁰. Optical density is related to opacity and transmittance as follows:

Scattering and
Absorption

Optical
Density

$$(\text{optical density}) = D = \log_{10} \frac{1}{1 - \text{opacity}} = \log_{10} \frac{1}{T} = \frac{naQl}{2.303}$$

In terms of particulate concentration (c) instead of the particulate number density (n), the expression can be written:

$$D = \frac{A_E cl}{2.303}$$

Where $A_E = \pi r^2 Q/m$, specific mass extinction coefficient
r = radius of the particle
m = particle mass

This expression is important in that it shows that the optical density is directly proportional to the particulate matter concentration and the pathlength. If the pathlength should be increased, the optical density will increase by the same factor (i.e. if the pathlength is doubled, the optical density will also double); also, if the concentration changes by some factor, the optical density will change by that same factor.

The optical density is important in opacity monitoring. It is related to the base ten logarithm of the inverse of the transmittance:

$$D = \log_{10}(1/T) = -\log_{10}(1 - Op)$$

or

$$Op = 1.0 - 10^{-D}$$

This will be important in discussions of opacity monitors later in this manual.

204.1.5 Fluorescence

Fluorescence (photoluminescence) is a photoanalytical process in which the light energy of the analytical beam is absorbed and the energy is re-emitted at a different wavelength¹⁵. In the process the molecules remain in the high energy excited state for a short time (10^{-8} to 10^{-4} s) during which time a small amount of energy is dissipated by vibrational and rotational motions. The result is that the re-emitted light energy is at a longer wavelength. In this way excitation and analysis wavelengths are separated, giving a measurement tool.

Light
Re-Emission

Chemical Reactions

204.1.6 Chemiluminescence

Chemiluminescence is a process in which a gas-phase chemical reaction produces a measurable light.¹⁵ In most cases the light is very weak, therefore, the detector must be shielded from extraneous light. The dark current of a photomultiplier tube can be reduced, and analytical sensitivity improved, if the photomultiplier tube is maintained at a constant low temperature.

One disadvantage of chemiluminescent techniques is that they require a supply of reactant gas. In the ethylene-ozone reference method for ambient ozone monitoring, a supply of ethylene gas must be maintained. In most chemiluminescent NO_x monitors, the ozone reactant gas is generated within the analyzer by photodissociation of atmospheric oxygen, negating the requirement for an external gas supply. The reaction chamber must remain very clean to prevent extinction of the excited molecules on the walls of the chamber rather than via light emission. The walls of the reaction chamber are usually specially treated to minimize this extinction.

204.1.7 Flame Photometry

In flame photometry a flame (usually hydrogen/air) is used to excite the pollutant molecules¹⁵. The major use of flame photometry is in hydrocarbon monitors (Page 200.54). The typical detector used with flame photometry is a FID (flame ionization detector). The FID measures the current flow (approximately 10⁻¹² amps) in the flame when pollutant molecules are ionized.

204.2 INSTRUMENTS

The fact that gas molecules will absorb or emit light at specific wavelengths has been used to design many pollutant monitors. As was discussed previously, the basic measurement principles are straightforward; however, possible interferences must be taken into account when an emissions monitoring system is designed. The pollutant gas being monitored must be analyzed in the midst of the other constituents in the stack. This may include particulate, moisture, other pollutants, and natural components. There is a significant possibility that these other components will interfere with the analysis in question. The analyzers must also be able to withstand the industrial environment and continue to operate for extended periods of time.

There are many types and models of analyzers on the market. It is important to understand their operating principles in order to make an appropriate choice of which to use.¹⁵ Remember that CEM systems are approved on an application specific basis rather than generically.

204.2.1 Nondispersive Infrared Analyzers (NDIR)

Because of their simplicity, nondispersive infrared analyzers are frequently used. The term 'nondispersive' refers to the fact that a filter is used to select the wavelength of light for use in the analysis rather than a diffraction grating. A diffraction grating spreads, or disperses, the spectrum so a narrow band of light wavelengths can be selected. The filter allows the selected wavelength to pass through it; the remaining wavelengths are absorbed.

Filters

Table 204.1
Infrared Absorption Bands of Common Pollutant Gases

Gas	Location of Absorption Bands (μm)
SO ₂	19.04, 8.70, 7.41, 4.00
NO	13.33, 9.52, 7.41, 6.15, 5.35, 3.45
CO ₂	14.81, 4.26, 2.76, 2.68
CO	4.65
HCl	3.45
H ₂ O	6.25, 2.70

Infrared methods probably have been used for more pollutant species than any other method. Analyzers to measure SO₂, NO, CO, HCl, CO₂, and water vapor, as well as some hydrocarbons have been developed. Table 204.1 shows some of the absorption band of pollutants monitored by infrared methods. Note that some gases might have absorption bands that overlap with others. In specific, both SO₂ and NO have absorption bands at 7.41 μm, and CO₂ and H₂O have bands that are too close to differentiate (2.68 μm vs 2.70 μm). These overlapping regions present potential interferences; i.e. analysis at 7.41 μm will measure the total of the SO₂ plus the NO.

In a typical NDIR instrument (Figure 204.5), infrared light is emitted from a source such as a glowbar. The light is transmitted through reference and sample cells. The reference cell is filled with an inert gas (such as nitrogen) or clean,

pollutant free air which passes the light unattenuated to give a reference value of the full initial light intensity (I_0).

The gas to be monitored is passed through the sample cell. The light passed through the sample cell is attenuated by absorption by the pollutant molecules (I). From the difference in light intensity the pollutant concentration can be calculated with the Beer-Lambert law (Page 200.37).

There are a number of IR detectors used. Most commonly, infrared monitors use pneumatic detectors.

204.2.2 Gas Filter Correlation Analyzers (GFC)

A variation of the NDIR technique is the gas filter correlation analyzer (GFC). Like the NDIR, the GFC is a Beer-Lambert law type device. However, in the GFC the absorption of light due to the pollutant gas is compared to a reference that is 100% absorbance rather than 0% absorbance. In the GFC technique¹⁶ (Figure 204.6) a relatively narrow light beam (but not restricted to the wavelengths absorbed by the pollutant gas) is intercepted by a rotating gas filter wheel. The filter wheel is partitioned into a reference sector and a measurement sector. There is usually also a dark sector for correction of variation of the electronics. The reference sector contains a 100% concentration of the pollutant gas which removes virtually all the light in the wavelengths in which the pollutant is active. The measurement sector contains a neutral gas (usually nitrogen).

Gas Filled Filter

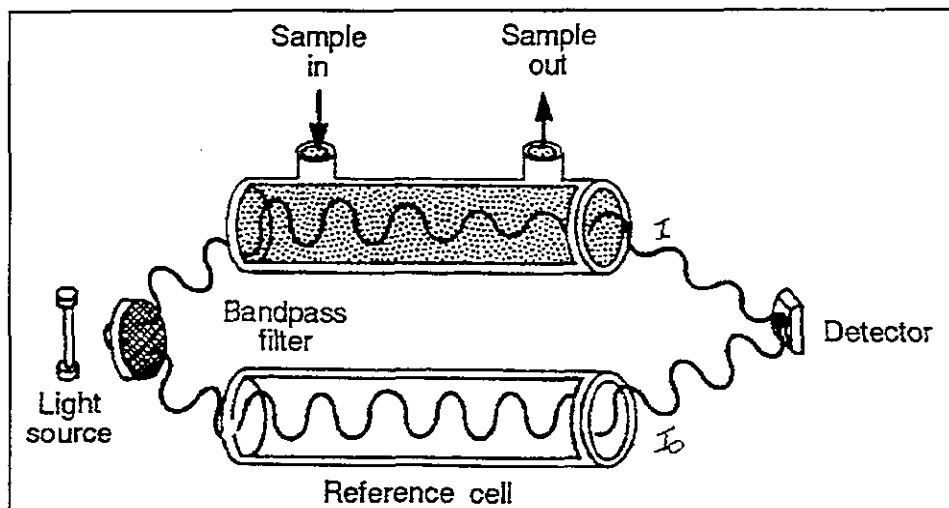


Figure 204.5 Simplified Diagram of an NDIR Analyzer³

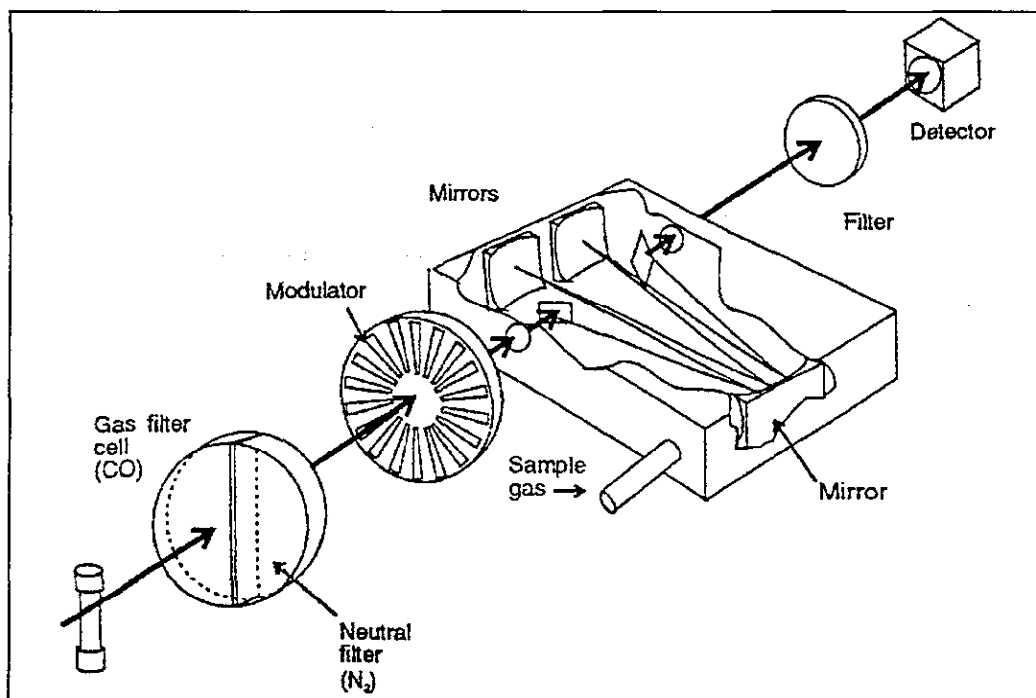


Figure 204.6 Gas Filter Correlation Analyzer Optical Chamber (Dasibi)¹⁶

When the light beam is intercepted by the reference sector of the gas filter wheel, virtually all the light in the wavelengths of light in which the pollutant is active is absorbed, rendering the remaining light insensitive to the pollutant (Figure 204.7). This gives a 100% absorbance reference signal. When the measurement sector rotates into the light beam, only a portion of the light is absorbed by the pollutant to the degree dictated by the concentration of the pollutant gas in the sample stream. Gaseous species other than that of interest will attenuate both the reference and measurement signals equally and so will be canceled out.

A third portion of the gas filter wheel is blacked out to provide a dark sector. This dark sector provides a zero light reference to compensate for the dark current of the detector and electronics.

In most GFC analyzers the light enters a sample cell containing several mirrors. The light passes back and forth through the sample gas a number of times (typically 32 passes) which has the effect of extending the pathlength for absorption. For example, if the light makes 32 passes in a 25 cm optical table, the total

Folded Path

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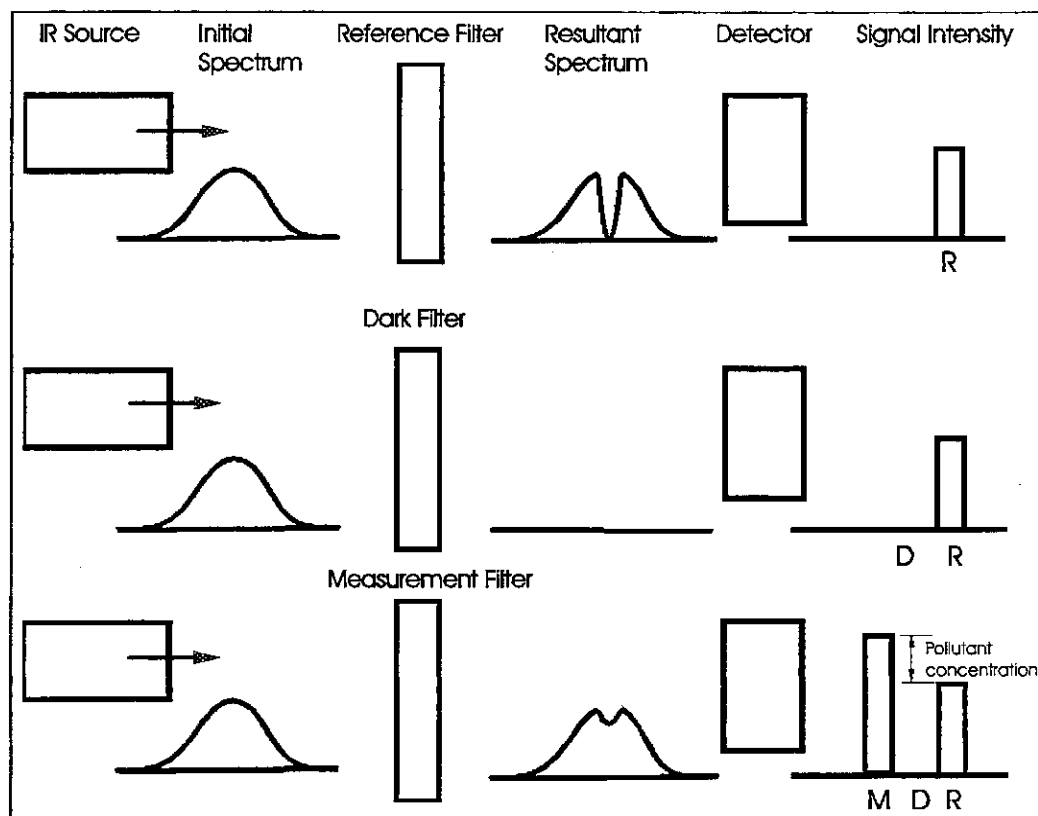


Figure 204.7 GFC Absorption Principles

pathlength will be 8 meters (800 cm). This gives the analyzer a far greater sensitivity while maintaining a compact device.

Gas filter correlation analyzers have been designed for monitoring SO_2 , NO , CO_2 , CO , ammonia (NH_3), water vapor, and HCl . The most common monitors for CO are GFCs.

There are several advantages of a GFC over a conventional NDIR analyzer. Because of the broader spectrum of light used, the method is not limited to a single absorption peak if there are several close together. The analyzer can measure over the broader spectrum, allowing the light from several absorption peaks to reach the detector, allowing more light to reach the detector. With the larger signal, simpler, more accurate, solid-state detectors can be used rather than chamber-type detectors. Also, because a ratio is obtained between the reference and measurement beams, biases in light intensity will cancel out, eliminating problems with infrared source instability and dirt accumulation on the optics.

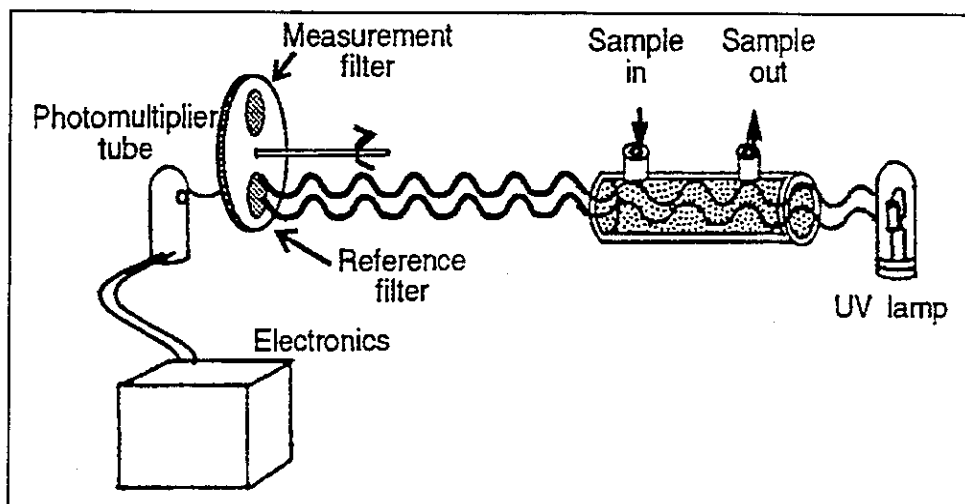


Figure 204.8 Operation of a Typical NDUV Analyzer³

The GFC can be used to monitor several pollutant gases at the same time. By using additional reference gas sectors (with 100% concentrations of the gases to be monitored) up to eight pollutant gases have been monitored simultaneously. Although they are not commonly available, such multi-component analyzers have the potential to reduce monitoring system costs.

204.2.3 Nondispersive Ultraviolet Analyzers (NDUV)

Nondispersive ultraviolet analyzers (NDUV) are very similar to NDIR analyzers; however, they use ultraviolet light rather than infrared. There are also a number of other differences due to the characteristics of ultraviolet light¹⁵.

The region of the ultraviolet spectrum in which practical analyzers operate extends from approximately 200 nm to 380 nm. This portion of the UV spectrum is considered the "near ultraviolet" being near the visible range. The region of shorter wavelengths (less than 200 nm) is considered to be "vacuum ultraviolet". Since oxygen interferes with the analysis in the vacuum UV range, analysis must be conducted in a vacuum, design of monitoring instruments in this range is infeasible for that reason. Vacuum UV also can cause the stack gas molecules to dissociate. Wavelengths longer than 400 nm are in the visible range.

Near UV

At the short wavelengths of UV radiation photons interact with the outer electrons of gas molecules, raising their energy levels. Other energies imparted to the

molecules at longer wavelengths cause bond vibration and rotation interactions. All three effects superimpose so it becomes impossible to separate them. As a result, UV spectra tend to be spread over a range of wavelengths rather than having a sharp peak. On the other hand, the available UV radiation sources (typically mercury vapor lamps and hollow cathode lamps) offer line spectra rather than a continuous spectra such as that of an IR blackbody radiation source. Additional spectral lines can be emitted by using phosphor compounds selected to emit light in the wavelength required for the analysis.

NDUV analyzers are commonly used in ambient monitoring to measure ozone. Sulfur dioxide and occasionally nitrogen oxide analyzers utilize NDUV in stack monitoring.

A typical differential absorption NDUV analyzer uses a single cell for both sample and reference measurements. Light from a UV source is alternately filtered to pass a wavelength in which the pollutant is active and a wavelength at which there is no absorption (Figure 204.8). For an SO₂ NDUV analyzer, the measurement wavelength is 285 nm and the reference wavelength is at 578 nm.

204.2.4 Fluorescence Analyzers

Photoluminescence

Fluorescence is a photoluminescent process in which light energy is absorbed at one wavelength and emitted at a different wavelength¹⁵. In this process the excited molecule will remain excited from 10⁻⁸ to 10⁻⁴ seconds. In this time some of the energy will be dissipated by rotational and vibrational motions, resulting in the emission light being lower energy (longer wavelength). Figure 204.9 illustrates this process.

Since the energies of the light emissions will be lower than the excitation energy, the emission wavelength will be longer. The fluorescence process for SO₂ can be expressed as:

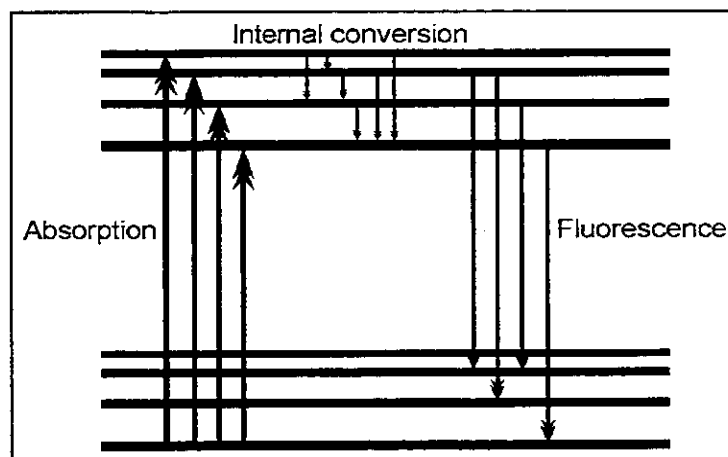
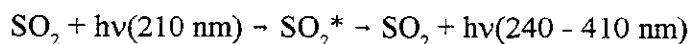


Figure 204.9 Energy Levels and Fluorescence



In a typical fluorescence analyzer (for example for SO_2 , Figure 204.10) the radiation is filtered to a narrow region. For SO_2 the region used is centered near 210 nm. There are three regions where SO_2 absorbs in the UV: 1) 340 - 390 nm, 2) 250 - 320 nm, 3) 190 - 230 nm. The first region exhibits only weak absorption and heavy quenching of the resulting fluorescent radiation. In the second region SO_2 absorbs strongly; however, the fluorescence is strongly quenched by oxygen and nitrogen in the air. The third region absorbs strongly and is only minimally quenched. Therefore, the third region is used for SO_2 fluorescence analyzers.

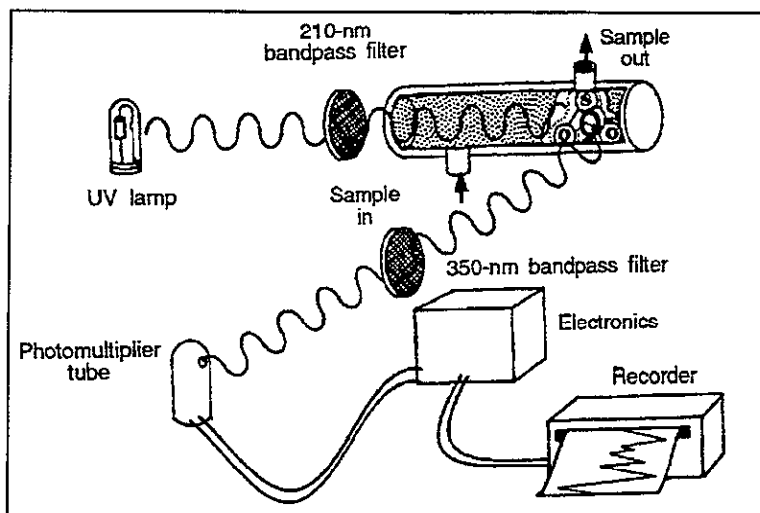


Figure 204.10 Typical Fluorescence Analyzer³

The fluorescent emission light is measured at right angles to the sample. The fluorescent emissions from SO_2 are in a range from 240 to 410 nm; a bandpass filter is used to select a portion of that light centered on 350 nm. At about 350 nm the spectrum is clear of most interferants.

One disadvantage of fluorescent measurements is fluorescent quenching. Water, CO_2 , O_2 , N_2 , hydrocarbons, and many other types of molecules can quench the fluorescence. This is a significant problem in many stacks since the concentrations of the quenching molecules can be quite high. However, most CEM systems have dryers and scrubbers to remove water and hydrocarbons.

It is also important to calibrate the analyzer with standards made up in a gas mixture similar to the background mixture being analyzed; i.e. the calibration standards should be made up in air rather than in nitrogen. Spanning an instrument with a standard in nitrogen rather than air could give as much as 30% lower readings than the true values.

Matrix Effects

200 CEM THEORY AND DESIGN

204.2.5 Chemiluminescent Analyzers

Chemiluminescence analyzers operate on the principle that certain gas phase chemical reactions generate light¹⁵. NO_x monitoring is the most important use of chemiluminescent methods in emission monitoring.

The chemiluminescent NO_x method uses the reaction of ozone and NO to produce a visible to infra-red light. This light is in the range from approximately 500 to 3000 nm; for analysis a filter is used to select light from 600 to 900 nm.

The ozone required for this reaction is generated within the analyzer, no cylinders of expendable gases are required.

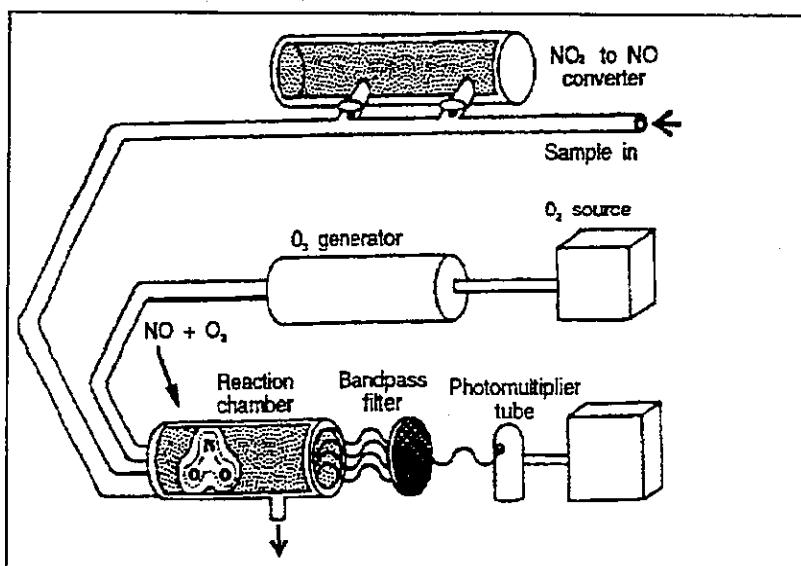
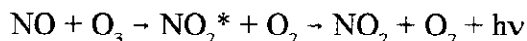


Figure 204.11 Chemiluminescent NO_x Analyzer³



It's important to note that the gas phase reaction only occurs with NO. Nitrogen dioxide does not react with ozone. In order to monitor NO₂, the NO₂ is reduced to NO in a heated catalytic converter. The converter is generally made of stainless steel or molybdenum, which causes the NO₂ to decompose when heated. Molybdenum chambers are more frequently used since they catalyze the reaction at lower temperatures. A molybdenum chamber is operated at approximately 350°C. To calculate the concentration of NO₂, the concentration of NO is subtracted from the total oxides of nitrogen. It is assumed that NO and NO₂ vastly predominate over other nitrogen oxide species.

The NO_x emissions from most combustion sources requiring monitoring are dominated by NO. The most significant exception is turbines. Since they are

operated at a high level of excess air, the emissions from turbines contain significant concentrations of NO_2 . When designing the CEM system this is important when selecting the moisture knockout since liquid water will readily absorb NO_2 .

In a chemiluminescent NO_x analyzer (Figure 204.11), ozone is generated by UV irradiation of atmospheric oxygen in a quartz tube. The ozone is provided in excess in the reaction chamber to ensure complete reaction and to minimize the effects of quenching. The light generated by the reaction is filtered by a bandpass filter and the signal measured by a photomultiplier tube.

Because the photomultiplier tube signal is proportional to the number of NO molecules undergoing the reaction (rather than the NO concentration), the sample flow rate control and pressure regulation is of critical importance.

The chemiluminescent radiation can be quenched, as in fluorescence instruments, causing a low bias in the results. The quenching can be minimized by using a high flow rate of ozone and operation of the reaction chamber under reduced pressure.

The results can also be biased by oxides of nitrogen other than NO and NO_2 . Ammonia (NH_3) will also bias the results since it will oxidize to NO in the converter. Using a molybdenum converter reduces this bias because of its lower operating temperature.

204.2.6 Opacity Monitors

Opacity monitors, or transmissometers, are probably the most common type of monitoring system. Opacity monitors measure the transmittance of light as it passes through a flue gas. The principles of opacity and light absorption are discussed in Section 204.1.4.

A transmissometer can be constructed as a single or double pass instrument. In a single pass instrument (Figure 204.12), the light passes once through the stack from a source on one side to a receiver on the other side. These instruments can be inexpensively manufactured, however, they generally do not satisfy the EPA design criteria for system zero and calibration checks. Single pass opacity monitors are often used as baghouse monitors where they can alert the source operators about the condition of the particulate removal system, but the monitor is not required to meet the EPA design criteria. Without the use of some artifice, such as a zero pipe to seal the flue gases from the light path during the zero or calibra-

Biases

Single Pass Transmissom- eters

tion check or a fiber optic light pipe to carry the light around the stack to the detector, the operator is hard pressed to obtain a clear stack through which to conduct the checks.

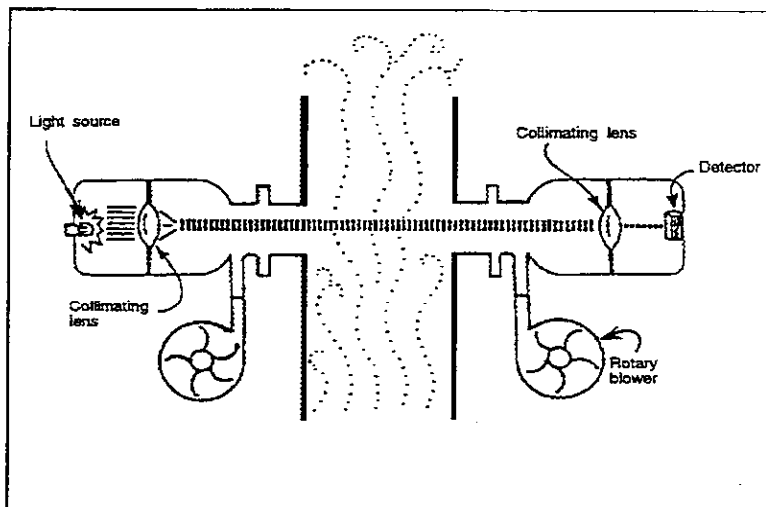


Figure 204.12 Single Pass Transmissometer³

Double Pass Transmissom- eters

A double-pass transmissometer (Figure 204.13)

design houses both the light source and detector in a single housing, the transceiver. A retro-reflector is mounted on the opposite side of the stack the reflect the light back to the detector. These instruments have added sensitivity since the pathlength is doubled. A double-pass transmissometer satisfies the EPA design criteria for system zero and calibration checks by use of a zero mirror to simulate a clear stack. The zero mirror is part of the transceiver assembly and reflects the light back to the detector without passing through the stack. This process can check all the electronic circuitry, including the lamp and detector.

Blowers

Transmissometers rely on blowers to maintain a positive pressure in the transceiver and retro-reflector housings relative to the stack pressure to prevent accumulation of dirt on the windows, mirrors, etc. These purging systems are critical to prevent accumulations on the windows from causing spuriously high readings. If the blowers should fail, most systems are equipped with shutters or flaps that automatically close to seal the instrument from the stack flue gas. The condition and operation of the blowers and the frequency of cleaning the windows are important factors for an inspector to examine.

Neutral Density Filters

Calibration checks of transmissometers are accomplished through the use of neutral density filters, which partially block light from the source from reaching the detector. These neutral density filters are similar to sunglasses of differing blocking strength. During the calibration check cycle, the zero mirror rotates into place, giving a zero opacity. Then each neutral density filter is rotated into place in the light beam to give upscale readings.

200 CEM THEORY AND DESIGN

Continuous
Emission
Monitoring

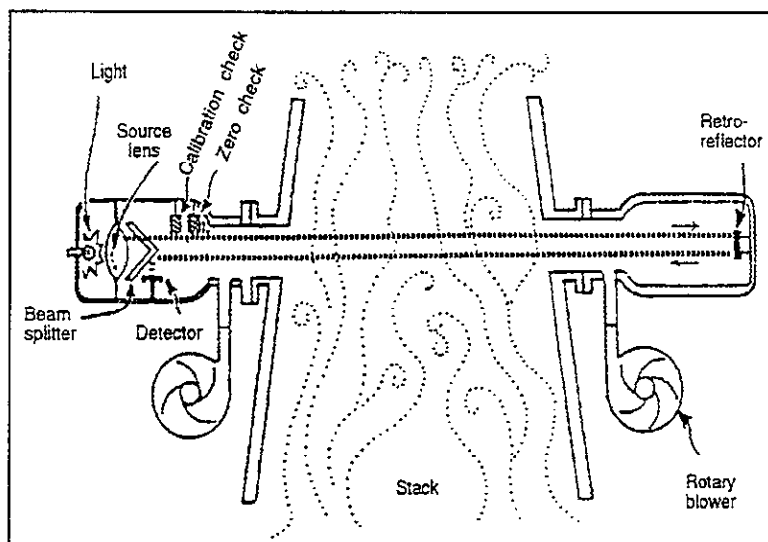


Figure 204.13 Double Pass Transmissometer³

In most systems, a chopper is used to provide a modulated signal. The chopper generally is a segmented wheel that alternately blocks light from entering the stack (and reflects it back to the detector, like the zero mirror) and allows the light into the stack. Thus, the output signal oscillates

Chopper

between zero and the flue gas opacity measurement. The modulated signal eliminates much of the interference caused by stray light entering the system.

As with gas analyzers, the EPA does not generically certify opacity monitors since each monitor installation is unique with its own unique monitoring problems. However, Performance Specification 1 (PS1) for opacity monitors differs from performance specifications for gas monitors in that PS1 relies heavily on specifying design criteria rather than performance testing (see Section 301.1).

205 GAS CHROMATOGRAPHY

Gas chromatography is a physical method for separating components in a mixture commonly used to monitor hydrocarbon emissions¹⁷. Since hydrocarbon regulations generally apply only to non-methane hydrocarbons, a method to separate the methane from the non-methane hydrocarbons is required. Gas chromatography (GC) fits that need. The basis of the method lies in the separation column, which is usually a small diameter tubing packed with a stationary bed with a large surface area. The mobile phase (consisting of the sample and a carrier gas) percolates through the stationary phase.

**Methane/
Non-Methane
Separation**

The basic process responsible for the separation lies in differential retention of the sample on the stationary phase. The retention may be based on adsorption, solubility, chemical bonding, polarity, or molecular filtration properties. How-

**Differential
Retention**

ever, in all cases, the retention is reversible. The sample molecules are reversibly retained on the stationary phase in proportion to the sample, stationary phase, and carrier gas properties. At the outlet of the column the compounds in the sample will have been separated based on their retention properties on the column in use, with some compounds being retained longer than others (Figure 205.1).

By using different column packing materials, temperatures, or column dimensions the rate at which a sample travels through the column (elution rate) can be controlled. If desired, a GC can be used to separate all components of the sample to obtain a complete analysis of the presence and concentration of every hydrocarbon in the sample.

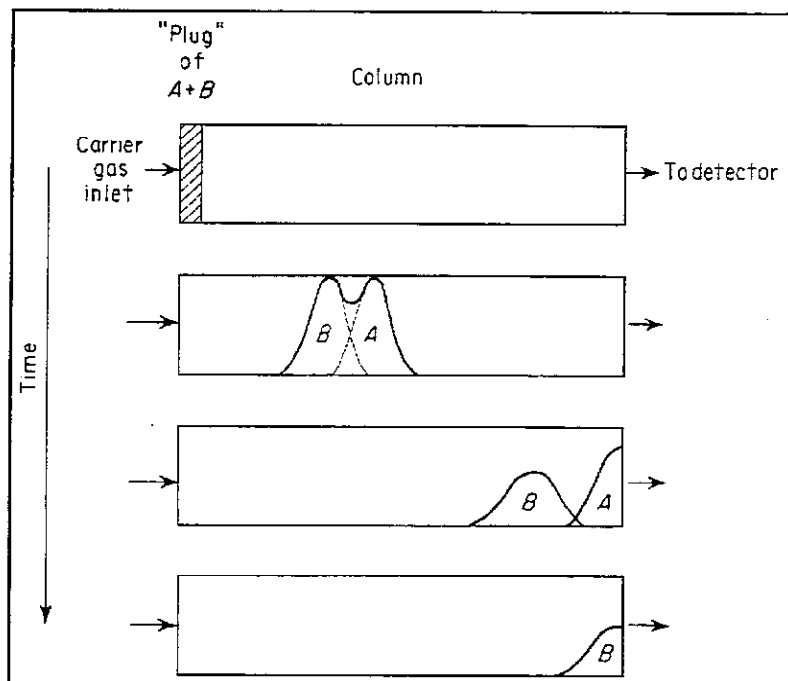


Figure 205.1 Gas Chromatographic Elution¹⁷

Elution

Temperature

The temperature of the column is important to sample compound separation. The higher the temperature the faster the sample will elute through the column. At high temperatures, however, the separation of hydrocarbon compounds will decline. The temperature at which the GC is operated must be high enough for rapid sample elution, but low enough to separate the methane from non-methane hydrocarbons.

FID

Upon emerging from the column, the separated sample enters the detector. A flame ionization detector (FID) is commonly used in ambient air monitoring (Figure 205.2). As the sample enters the detector, hydrogen fuel is mixed with the sample and air is mixed axially around the jet. The hydrogen flame burns at the tip of the burner and ionizes the molecules in the sample. The burner serves as a cathode and a loop of wire above the flame serves as the anode. An electri-

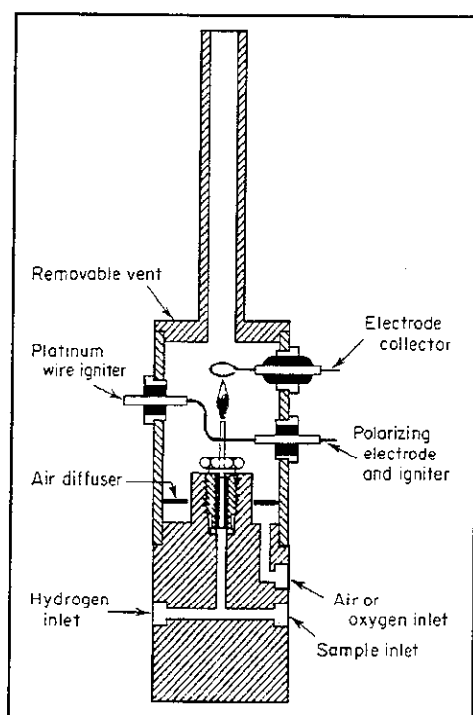


Figure 205.2 Flame Ionization Detector¹⁷

cal current between the burner and the wire anode is formed in the flame. The typical current is about 10^{-12} amps.

The FID is essentially a carbon counter. A large, complex hydrocarbon will generate a larger signal than a small hydrocarbon with few carbon atoms. If the specific compound is known, the output of the FID can be calibrated to the number of carbons in that compound. Otherwise, the output is generally stated relative to a reference compound; i.e. stated as "measured as hexane".

The FID is quite sensitive to hydrocarbon compounds and insensitive to water, inorganic compounds, and background gases in the air and most stacks.

206 ELECTROANALYTICAL AND MAGNETIC METHODS

Another class of monitoring instruments is based on electrical and magnetic principles to determine gas concentrations. The magnetic methods measure the magnetic behavior of the gas in response to a magnetic field and can be divided into thermomagnetic, magnetodynamic, and magnetopneumatic instruments. The electroanalytical methods measure an electrical current in response to the pollutants in the analyzer.

The most common use of these analyzers is to measure oxygen concentrations. Oxygen is important as a diluent gas. Many permits and regulations require that the pollutant gas emissions be reported at a specific oxygen concentration. In this manner excess combustion air, air infiltration leaks, and sample dilution can be accounted for.

206.1 ELECTROANALYTICAL METHODS

Electroanalytical measurements can be divided into polarographic and electrocatalytic methods. Polarographic methods can be inexpensive and por-

Electrochemi-
cal Cells

table, which is ideal for inspection applications. The electrocatalytic or high-temperature fuel-cell method is used exclusively to monitor oxygen. These methods can be used either in extractive or in-situ applications.

206.1.1 Polarographic Analyzers

Polarographic analyzers (also known as voltametric or electrochemical transducers) are self-contained electrochemical cells which operate much like batteries. In these devices a reaction with the pollutant molecules takes place resulting in an electrical signal at the output of the analyzer. Polarographic analyzers are quite flexible, being able to monitor SO_2 , NO_x , CO , O_2 , and other gases depending on the electrodes and electrolytes employed. By varying the composition and potential of the electrode both quantitative and qualitative information can be obtained.

The sequence of events in a polarographic analyzer is: 1) diffusion of the gas through the semipermeable membrane, 2) dissolving of the gas in the thin liquid film, 3) diffusion of the gas through the liquid film to the sensing electrode, 4) an oxidation-reduction reaction at the sensing electrode, 5) transfer of the charge to the counter electrode, and 6) reaction at the counter electrode (Figure 206.1).

The rate at which the pollutant gas reaches the sensing electrode is controlled by diffusion and the type of membrane used. The current between the sensing electrode and counter electrode can be monitored as the pollutant gas concentration. The relevant equation, including Fick's law of diffusion is:

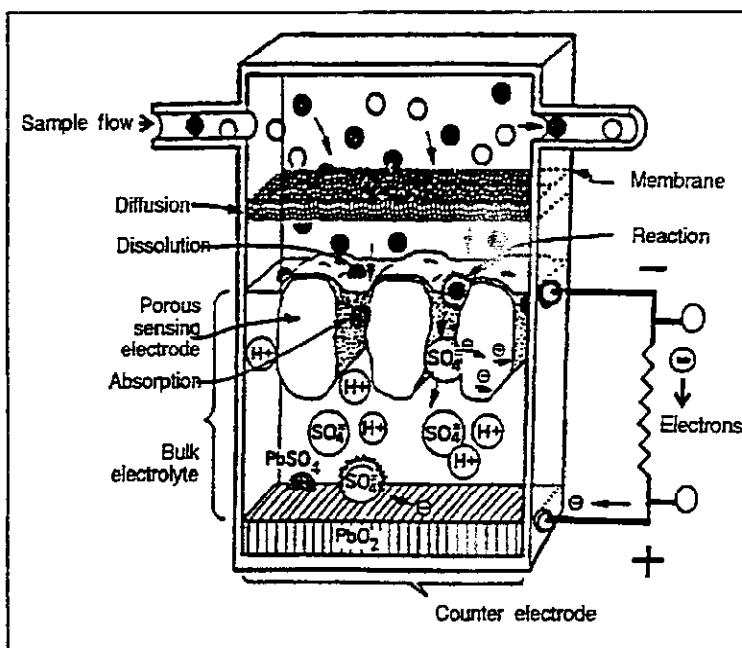


Figure 206.1 Polarographic Analyzer³

$$i = \frac{nFADc}{d} = kc$$

Where i = current

n = number of exchanged electrons per mole of pollutant

F = Faraday constant (96,500 coulombs)

A = exposed electrode surface area

D = diffusion coefficient of the gas in the membrane and liquid film

c = concentration of the gas dissolved in the electrolyte layer

d = thickness of the diffusion layer

k = constant

Fick's Law

A polarographic analyzer is temperature sensitive, and so the temperature must be carefully controlled. It is also important that the sample is well conditioned prior to being presented to the analyzer. Particulate and condensed water can easily foul the membrane, requiring it to be refurbished or replaced.

Temperature

As with batteries, the chemicals in the cell will eventually be depleted and it will have to be replaced. In emission monitoring applications the life of a polarographic analyzer cell is typically three to six months. Maintenance and replacement of the cells must be part of the routine maintenance procedures.

Depletion

206.1.2 Electrocatalytic Analyzers

Electrocatalytic analyzers are almost exclusively used as oxygen monitors. They are an outgrowth of fuel-cell technology, although not actually fuel-cells. These analyzers are simple electrolytic concentration cells that use a special solid catalytic electrolyte to aid the flow of electrons. They can be used in either in-situ or extractive systems. They are not applicable to dilution systems since they measure the oxygen concentration, which would be masked by the dilution air injected by the dilution process.

Catalytic
Electrolyte

In this method (Figure 206.2), a porous ceramic zirconium oxide (ZrO_2) material, coated with platinum and heated to approximately 850°C, serves as an electrolyte to allow the transfer of oxygen from one side of the cell to the other. The oxygen passes through the structure as O^{2-} ions, carrying two electrons between the electrodes. The process is dependent on the partial pressure (concentration) of oxygen on each side of the ZrO_2 barrier. A constant flow of stack gas and reference gas prevents the process from reaching equilibrium. The reference gas used is ambient air which is constant at 21% O_2 . Combustion gases are typically

Concentration
Gradient

200 CEM THEORY AND DESIGN

approximately 6% O₂, giving a gradient which translates into an electromotive force (emf) in the process which can be electrically measured.

$$\text{emf} = \frac{RT}{4F} \ln \frac{P_{\text{ref}}(\text{O}_2)}{P_{\text{sample}}(\text{O}_2)}$$

Where R = ideal gas law constant

F = Faraday's constant

T = cell temperature

P_{ref}(O₂) = partial pressure of O₂ in the reference side of cell

P_{sample}(O₂) = partial pressure of O₂ in the measurement side of cell

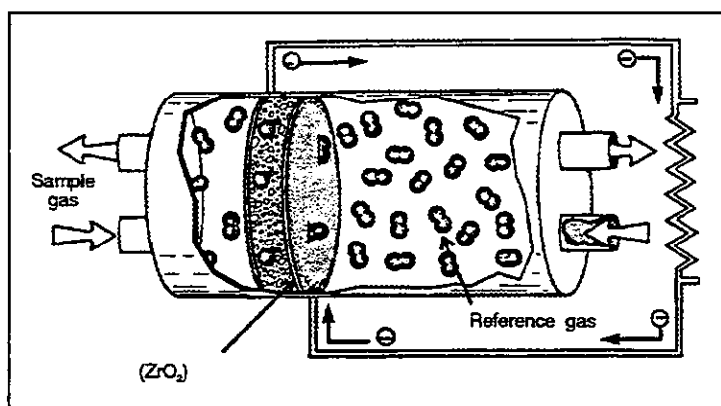


Figure 206.2 Electrochemical Oxygen Analyzer³

One problem in this method of gas analysis is that CO, hydrocarbons, and other combustible gases will burn at the temperature at which the cells operate, consuming oxygen, resulting in values lower than true. In most sources this is insignificant since

these contaminant gases are present in parts per million levels while oxygen is present in percent levels. The quantity of oxygen consumed, unless CO or hydrocarbons in the stack gas are in percent levels, will be undetectable.

206.2 MAGNETIC MONITORING METHODS

Oxygen, nitric oxide, and nitrogen dioxide are unique among the ordinary gases in that they are paramagnetic; that is, they are attracted into a magnetic field. Most gases are slightly diamagnetic - repelled out of a magnetic field. Oxygen is several times more paramagnetic (magnetic susceptibility of 146.6) than NO (65.2) or NO₂ (4.3 x 10⁻⁹). Coupling the greater magnetic susceptibility with the far greater concentration of oxygen (percent levels vs ppm levels) in stack gases, measurements of the magnetic properties of the gases give a means of monitoring oxygen concentrations.

Paramagnetism

Magnetic oxygen monitors are only used in extractive CEM systems since water and particulate matter must be removed before analysis.

206.2.1 Thermomagnetic Instruments

Thermomagnetic, or magnetic wind, instruments are based on the fact that the paramagnetic properties of oxygen decrease with increasing temperature. A typical analyzer utilizes a cross-tube arrangement with a heated filament (Figure

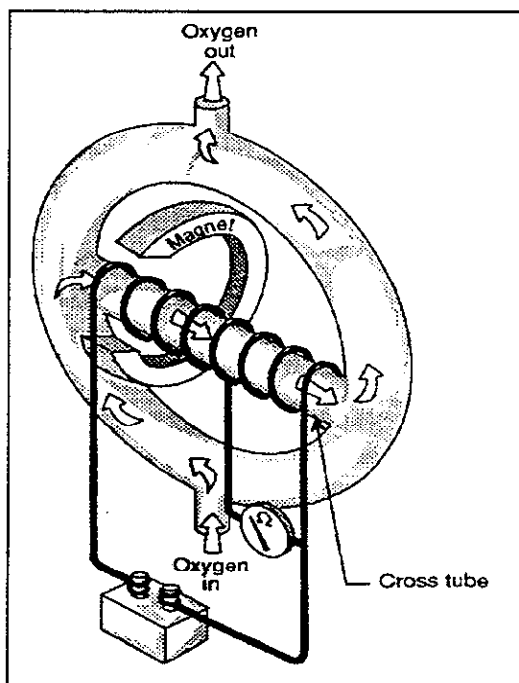


Figure 206.3 Thermomagnetic Oxygen Analyzer³

206.3). A strong magnetic field attracts oxygen into the cross-tube. The oxygen then heats up and its paramagnetic susceptibility is reduced. The heated, demagnetized oxygen is then pushed out of the cross-tube by additional incoming oxygen. As the gas flows past the following section of heated coils, the coils are cooled. The cooled coil has a different resistance, which can be measured by a Wheatstone bridge type circuit.

For these instruments to operate properly the thermal conductivity of the gases must remain constant; therefore, the composition of the gases must remain relatively constant. Also, unburned hydrocarbons may react on the heated coils and change their properties.

206.2.2 Magnetodynamic Instruments

Magnetodynamic instruments depend on the effect oxygen will have in modifying a magnetic field. A small diamagnetic glass dumbbell is suspended in a nonuniform magnetic field (Figure 206.4). When no oxygen is present, the magnetic forces exactly balance the torque on the fiber suspending the dumbbell. When a sample containing oxygen is drawn into the instrument the magnetic force is altered causing the dumbbell spheres to rotate away from the region of maximum magnetic flux density. The degree of rotation is related to the partial pressure of oxygen in the sample. Alternatively, a current can be sent through a loop of

platinum wire surrounding the glass dumbbell to create a counter electromagnetic field to restore the dumbbell to its reference position. The amount of restoration current necessary is related to the oxygen concentration.

206.2.3 Magnetopneumatic Instruments

In the magnetopneumatic oxygen monitor (also called a paramagnetic pressure sensor) the sample runs through a flat measuring cell and a reference gas (nitrogen) flows at an equal rate through channeling tubes (Figure 206.5). If oxygen is present it is attracted into the pulsed magnetic field, creating a pressure imbalance which can be measured by a microflow sensor.

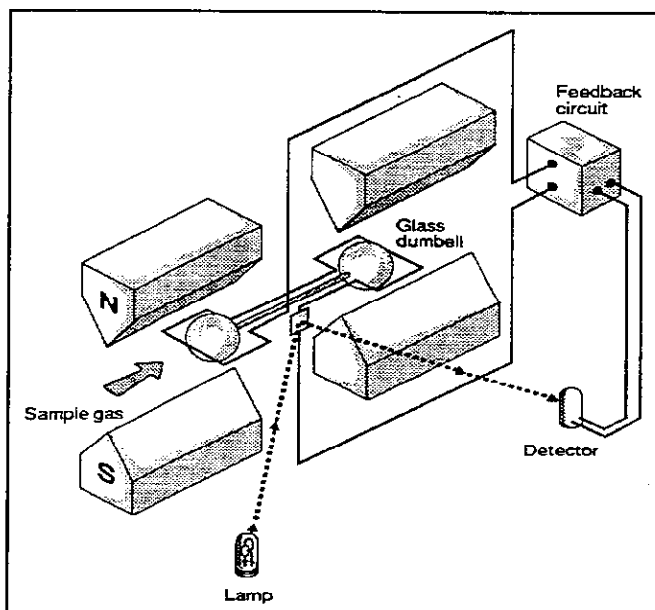


Figure 206.4 Magnetodynamic Oxygen Analyzer³

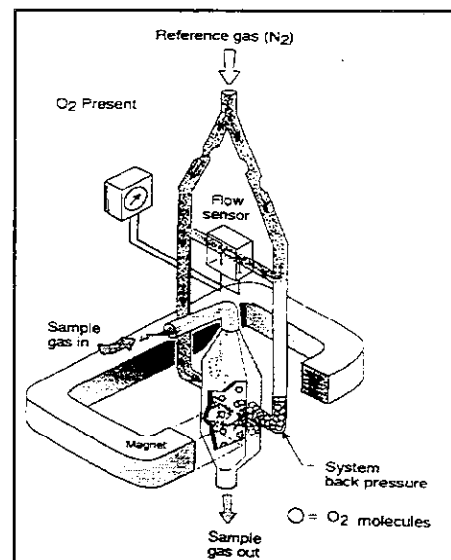


Figure 206.5 Magneto-pneumatic Oxygen Analyzer³

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300 INSTALLATION AND OPERATION

Continuous Emission Monitoring

For a CEM system to give quality data a good deal of thought and effort must go into its selection, installation, and operation. Since each source can vary significantly from any other, CEMs are not generically certified. Each system is designed to match the specific source configuration and constraints.

Gas monitors have very few design requirements;¹ essentially, if a gas monitor can do the job and pass all the required performance tests, it is an acceptable instrument. There are three general requirements for a gas monitoring system: 1) the system data recorder response range must include a zero and high level value, 2) the data recorder output must be established so that the high-level value is read between 90 and 100 percent of the data recorder full scale (this requirement may not apply to digital systems), and 3) the CEM's design must allow for the determination of both zero and high-level calibration drift.

Opacity monitors, on the other hand, have extensive design specifications detailed in EPA Performance Specification 1 (PS1)¹. The certification of opacity monitors depends on the design specifications rather than the extensive reference method testing employed with gas monitors.

A critical part of setting up a monitoring system is the selection of a monitoring location that will give representative data. A monitor may be able to operate adequately and may even pass its performance tests, but if the location at which it is installed is not correct, the data may not be useful. The location must also allow for ease of access for routine and emergency maintenance.

Finally, reliable operation of the CEM is dependent on calibrations, audits, and an extensive quality assurance plan.

301 INSTRUMENT SPECIFICATIONS

The specification and choice of a continuous emission monitoring system is critical to reliable operation of a facility's CEM program. Systems to be used for monitoring gases are only loosely specified by the EPA. These systems can readily be checked by using manual or instrumental reference test methods. However, for opacity monitoring there are no reliable or convenient independent methods for checking the accuracy of transmissometers. Therefore the EPA has set out extensive design and performance specifications so that measurements can be made accurately and uniformly from source to source.

CEM Design and Testing

Location

QA

300 INSTALLATION AND OPERATION

301.1 SPECIFICATIONS FOR TRANSMISSOMETERS

For transmissometers the specifications include requirements for:¹

- Spectral response (peak and mean)
- Angle of view
- Angle of projection
- Optical alignment sight
- Simulated zero and upscale calibration system
- External calibration filter access
- Automatic zero compensation indication
- Specification for instruments with slotted tubes

301.1.1 Spectral Response

Performance Specification 1 (PS1) requires that a transmissometer respond to light in the visible, photopic, range. The peak and mean spectral responses (Figure 301.1) must be between 500 and 600 nm. Also, the response at any wavelength above 700 nm and below 400 nm must be less than 10% of the spectral peak.¹

There are three basic reasons to specify that transmissometers measure in the visible (400 - 700 nm) region of the spectrum:^{2,3}

1. For comparability to visible emission evaluation readings, the instrument must measure in the visible range. The visible range extends from 400 nm (violet) to 700 nm (red).
2. Water vapor and CO₂ absorb light energy in the near infrared region of the spectrum. To avoid interference by water vapor and CO₂ those wavelengths must be excluded. Transmissometers generally use incandescent lamps as the

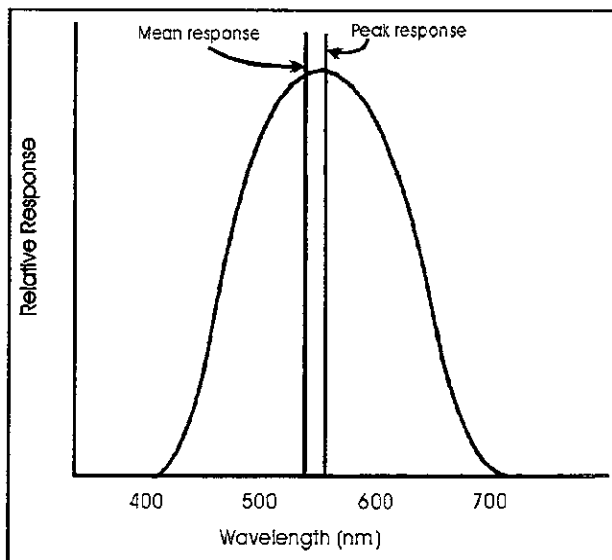


Figure 301.1 Transmissometer Spectral Response

**Peak Re-
sponse 500
nm to 600
nm**

**Less Than
10% Re-
sponse >400
nm and <700
nm**

light source; however, a combination of filters and selective detectors eliminates the extraneous wavelengths.

- Light scattering by particulate is dependent on the size of the particulate (d) and the wavelength of light (λ). This relationship is called the size parameter (α)⁴.

$$\alpha = \frac{\pi d}{\lambda}$$

For visible light the value of α is approximately equal to six times the particle diameter (in micrometers). Extinction efficiency decreases rapidly with decreasing α below a value of 2; i.e. small particles or long wavelength light.

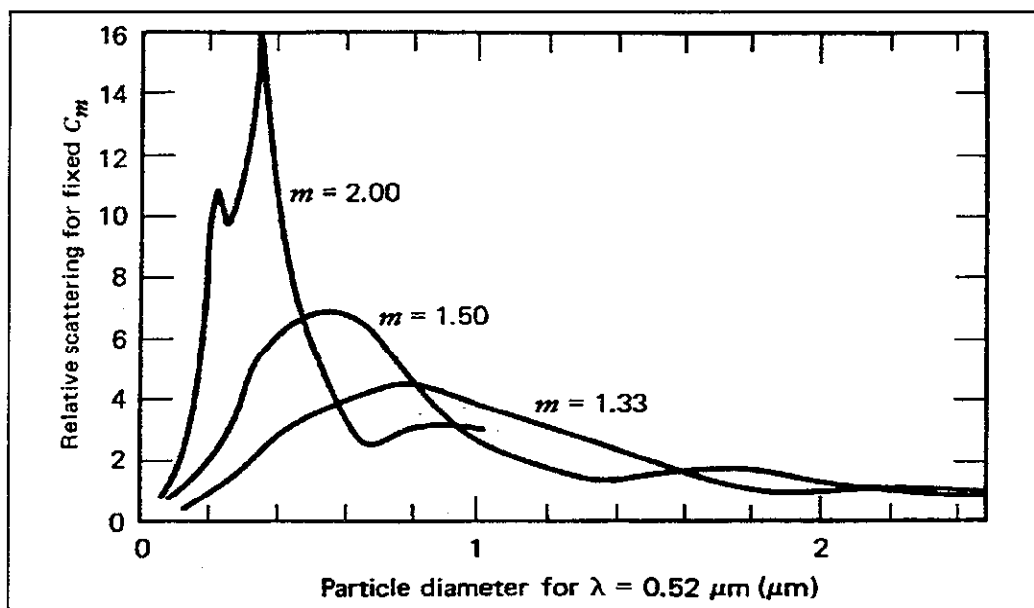


Figure 301.2 Relative Scattering Per Unit Mass of Aerosol vs Particle Size ($\lambda = 0.52 \mu\text{m}$, m = Index of Refraction)⁴

Light of 450 nm has a maximum Mie scattering coefficient for particles in the size range of 0.2 μm , whereas light at 1000 nm has a smaller scattering coefficient for 0.2 μm particles and a maximum scattering for 0.5 μm and larger particles².

**Particle
Diameter
and λ**

300 INSTALLATION AND OPERATION

Due to a particle's optical extinction efficiency, the visual impact of atmospheric aerosols and smokestack plumes is governed by the concentrations of particles between $0.1\ \mu\text{m}$ and $2\ \mu\text{m}$ (Figure 301.2). Beyond this range the light extinction efficiency declines. A reduction in concentration outside this range has little effect on extinction or visibility. Particulate controls at industrial plants can easily remove most of the larger particulate. However, particulate in the most optically active size range are often the most difficult to control. Because plume opacity results from light scattering from the small uncaptured particles, monitors must be designed to measure the loss of transmittance due to these small particles.

301.1.2 Angle of Projection and Angle of View

Angle of
Projection $<5^\circ$

The angle of projection (Figure 301.3) is the angle that contains all the radiation projected from the lamp and lens assembly at a level greater than 2.5% of the peak response.¹ If the lamp and lens system project a wide cone of light some of the light will be out of the view of the detector, however, some of the light beyond the angle of view of the detector will be scattered by the particulate back into the view. This will increase the measured transmittance and decrease the reported opacity.

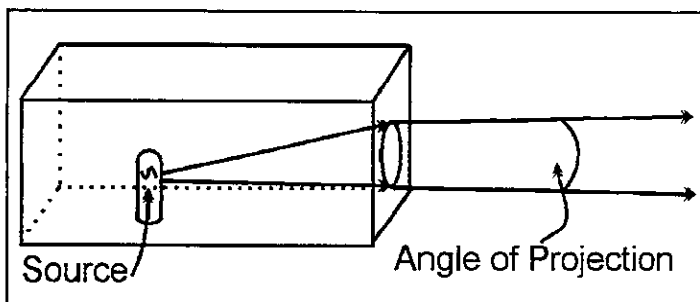


Figure 301.3 Angle of Projection

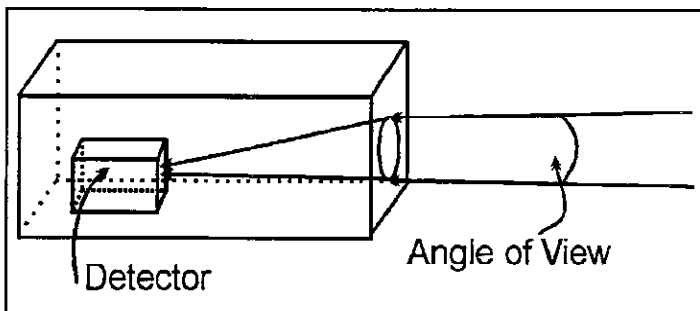


Figure 301.4 Angle of View

Angle of View
 $<5^\circ$

The angle of view (Figure 301.4) is the angle that contains all the radiation detected by the photodetector assembly at a level greater than 2.5% of the peak detector response.¹ If a detector has a wide angle of view it might measure light that has been scattered and would otherwise be lost to the analysis. This addi-

tional scattered light would be counted as increased transmittance and decreased reported opacity.

Performance Specification 1 requires that both the angle of projection and the angle of view be no greater than 5°.

301.1.3 Optical Alignment Sight

Transmissometers are required¹ to provide a means to visually determine whether the instrument is properly aligned. When misaligned, some light in a transmissometer will fail to be returned to the detector, resulting in an erroneously high opacity measurement. A satisfactory alignment sight will indicate a misalignment that results in less than 2% opacity error on a monitor pathlength of 8 meters. The most common alignment sight is a beam splitter that can be manually inserted into the measurement beam. Light returning from the retroreflector will reflect from the surface of the splitter to a bulls-eye sight on the side of the transmissometer. The alignment can be very easily checked during an inspection of the monitor.

301.1.4 Simulated Zero and Upscale Calibration

All continuous emission monitors must provide a means of calibration. As an inherently path in-situ monitoring system, the most practical means of calibration of an opacity monitor is to provide a simulated zero (no greater than 10% opacity) and upscale calibration. Simulated zeros and spans are used since a pollutant-free path is required without stopping operation of the facility process while the monitor is calibrated. At a minimum, the calibration system must provide a system check of the analyzer internal optics and all electronic circuitry including the lamp and photodetector assembly.¹

When the Air Resources Board calibrates the transmissometer used for visible emission evaluator training (a single pass path type instrument), the emission source is turned off during the calibration. However, this is impractical for an industrial source.

To provide a simulated zero opacity on double pass instruments, the most common practice is to insert a zero mirror at the exit of the transmissometer window (Figure 301.5). This mirror returns the light to the detector without crossing the stack. For the upscale calibration, a certified neutral density filter is placed in the light path (with the zero mirror blocking the beam).

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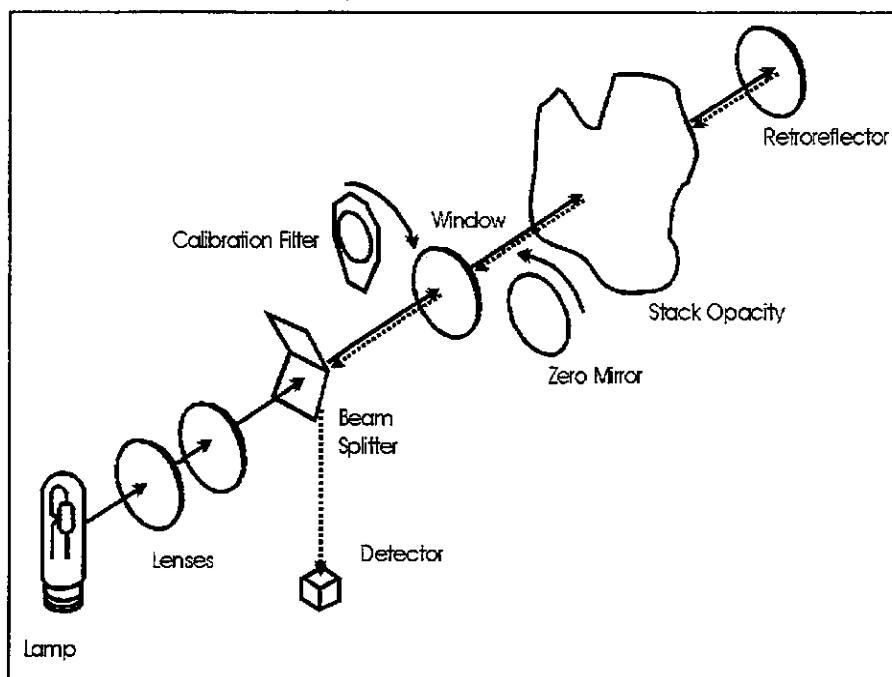


Figure 301.5 Transmissometer Diagram Showing Simulated Zero Mirror and Calibration Filter

301.1.5 Access to External Optics

Portions of the monitoring system are invariably going to be exposed to the stack gas stream. Blowers prevent the worst of the fouling, but even the best blower systems cannot keep these surfaces clean indefinitely. Access must be provided to clean these surfaces without requiring removal of the monitor from the source mounting or optical realignment.

301.1.6 Automatic Zero Compensation Indication

Transmissometers that provide a means of zero compensation to automatically compensate for particulate buildup on exposed optical surfaces must also provide a means of indicating the total amount of compensation invoked. This value must be available to the operator (e.g. on the data terminal). The performance specification limits¹ the total amount of compensation to 4%.

The performance specification also requires that, during the operational test period of the system certification, the actual amount of zero compensation must be determined so the true 24-hour drift can be determined.

**Automatic
Compensation
<4%**

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301.1.7 Slotted Tube Requirements

Occasionally a transmissometer will use a slotted tube to maintain optical alignment and allow a true zero and span of the instrument. A slotted tube can be closed and purged of effluent gases to provide clear stack conditions. The tube between the transceiver and retroreflector is subject to four principal requirements in PS1:

- The length of the tube must be equal to or greater than 90% of the effluent pathlength (distance between the stack walls).
- The tube must be of sufficient size and orientation so as not to interfere with the free flow of effluent through the entire optical volume of the transmissometer.
- The tube must be designed to minimize light reflections.
- The system must be demonstrated to comply with the requirements in a laboratory demonstration.

Exceptions to the 90% rule are allowed if the instrument can demonstrate that acceptable results can be obtained. As a minimum demonstration, the effluent opacity shall be measured with both the system being certified and a non-slotted tube transmissometer at the same location and operating conditions for a minimum of two hours each. The systems are deemed equivalent if the average opacities agree $\pm 10\%$, or the difference between the average opacities is less than two percent.

301.1.8 External Calibration Filter Access (Optional)

Provisions of the design of the transmissometer to accommodate an external calibration filter assembly are recommended. An adequate design would permit occasional use of external neutral density filters to assess monitor operation.

These provisions are very useful to the inspector. As part of a thorough inspection of the CEM systems an inspector should audit the monitors with external standards. By using a set of independently certified neutral density filters, the inspector can fully document the accuracy and precision of the CEM.

Audit Filters

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302 INSTALLATION GUIDELINES

Representative

The primary consideration when installing a CEM system is that the resulting data must be representative of emissions from the stack being monitored. This is true for all monitoring systems, including: gases, opacity, and rate monitors. Although each is handled slightly differently in their respective performance specifications due, in part, to the nature of the pollutants monitored.

Well Mixed

To assure a representative sample from the stack, the stack gases must be well mixed. Two factors contribute to a complete mixing: turbulence and time. The criteria discussed in this section represent conditions under which well mixed emissions can be expected.

Accessible

A significant secondary consideration when installing the CEM is that the system must be accessible. Often a compromise is required to achieve the most representative location that is also accessible. If the system is inaccessible, maintenance (both routine and emergency) is less likely to be performed on the monitor, owing to the difficulty in reaching it.

302.1 GAS MONITOR LOCATIONS

$\frac{1}{2}$ and 2 Stack Diameters

To minimize stratification in the gas flow, it is suggested that monitors follow the same requirements for the minimum distances between flow perturbations as source testing, i.e. a minimum distance upstream from stack effluent or other disturbance to the monitor of one half the diameter of the stack or duct. The minimum downstream distance should be at least two stack or duct diameters from the nearest control device, point of pollutant generation, or flow disturbance at which the pollutant concentration, characteristics, or distribution within the stack may be altered (Figure 302.1).

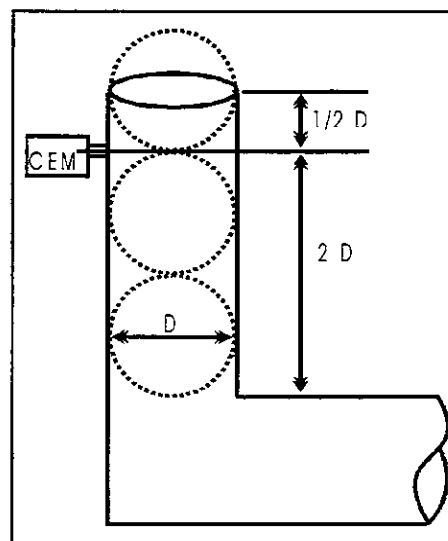


Figure 302.1 Minimum Spacing for Gas CEM Location

Point CEM

A point monitor should be: 1) no less than one meter from the stack wall or 2) centrally located over the centroidal area of the stack or duct cross section (Figure 302.2a and b).

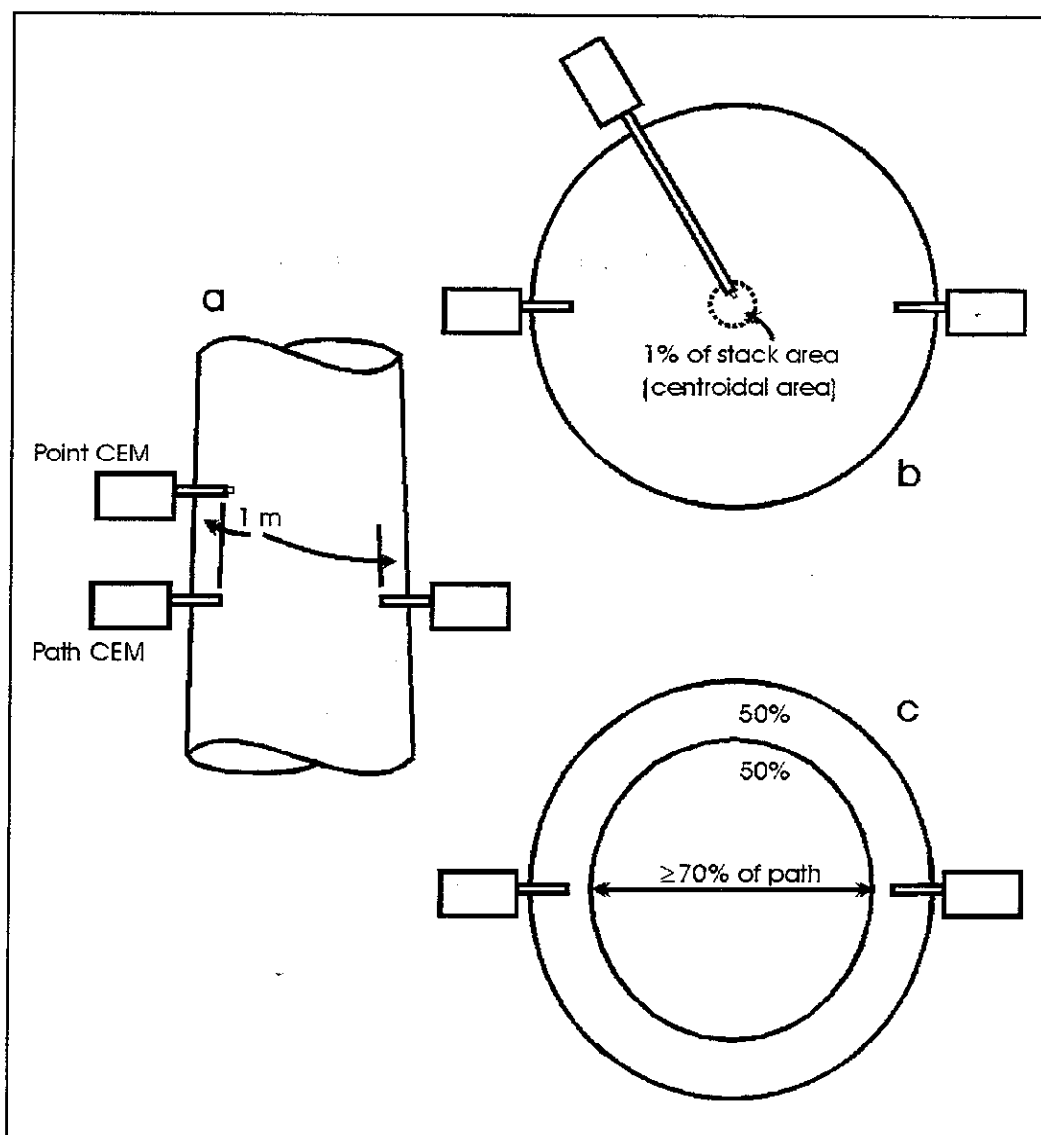


Figure 302.2 Location of Gas CEM, a) Point or Path CEM Measurement at Least One Meter from Stack or Duct Wall; b) Point CEM Within or Centrally Located Over the Centroidal 1% Area of the Stack or Duct, Path CEM Centrally Located Over Any Part of the Centroidal 1% Area; c) Path CEMs Must Have at Least 70% of the Path Within the Inner 50% of the Stack or Duct Cross Sectional Area¹

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Path CEM

The effective measurement path of a path CEM should be:

- 1) totally within an area bounded by a line one meter from the stack or duct wall, or
- 2) have at least 70% of the path within the inner 50% of the stack or duct cross-sectional area, or
- 3) be centrally located over any part of the centroidal area (Figure 302.2).

302.2 OPACITY MONITOR LOCATIONS

In addition to the previous requirements, transmissometers have several additional location and orientation requirements¹.

Although the path does not need to pass through the center of the stack, the monitoring site should be selected such that the measurement path passes through the centroidal area equal to 25% of the cross sectional area.

Centroidal 25%

The orientation of a transmissometer to any bends in the stack or duct is also important. The inertia of the light attenuating particulate matter can easily lead to stratification when the stack or duct does not have a sufficiently long straight section for complete mixing. As a generalization,

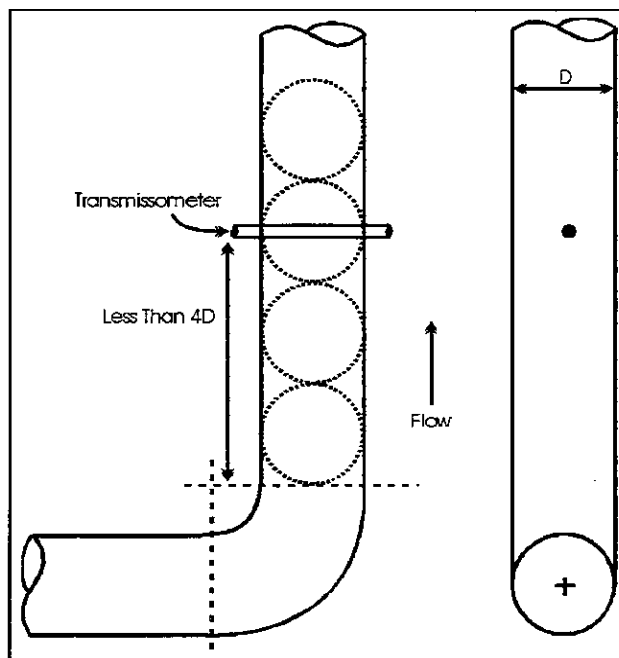


Figure 302.3 Transmissometer Location Downstream of a Bend in a Vertical Stack

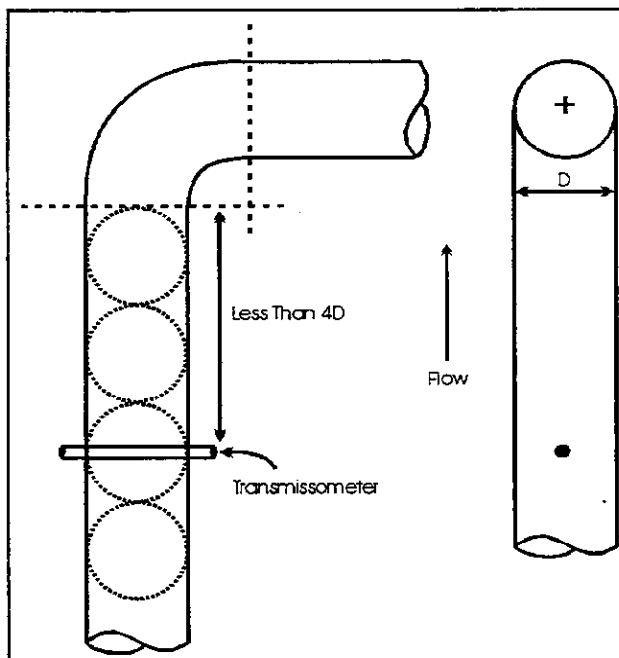


Figure 302.4 Transmissometer Location Upstream of a Bend in a Vertical Stack

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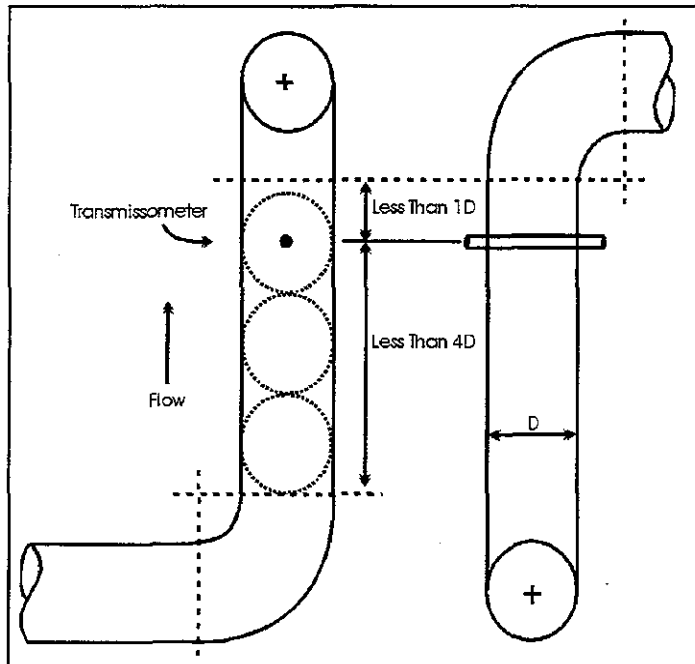
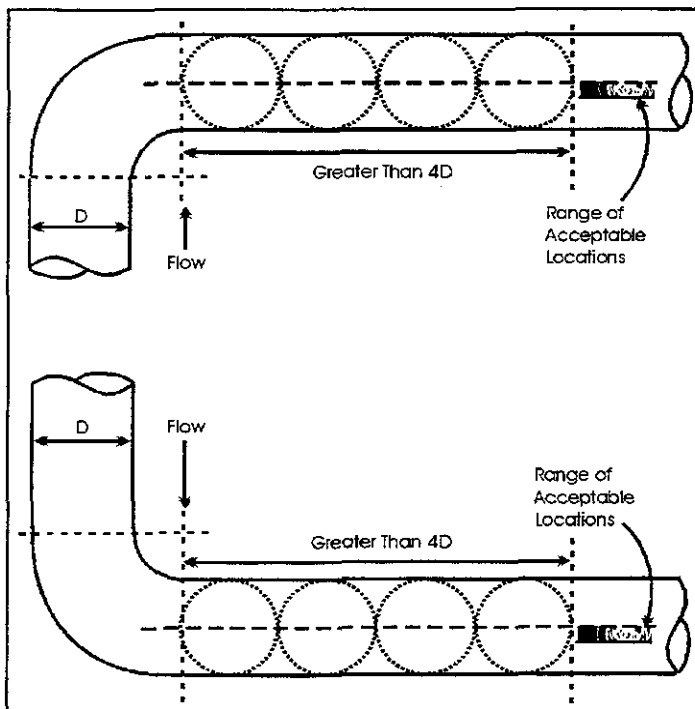


Figure 302.5 Transmissometer Location Between Bends of a Vertical Stack



the path should be oriented in the plane defined by the plane of the bend. More specifically:

- If the location is in a straight vertical section and is less than four equivalent diameters upstream or downstream of a bend, the path should be in the plane defined by that bend (Figures 302.3 and 302.4).
- If the location is in a straight vertical section and is less than four equivalent diameters downstream and is also less than one diameter upstream from a bend, the path should be in the plane defined by the upstream bend (Figure 302.5).
- If the location is in a straight horizontal section and at least four

Figure 302.6 Transmissometer Location Greater Than Four Diameters Downstream of a Bend in a Horizontal Stack

Plane of the Bend

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diameters downstream from a vertical bend, the path should be in a horizontal plane that is between one-third and one-half the distance up the vertical axis from the bottom of the duct (Figure 302.6).

- If the location is in a straight horizontal section and less than four diameters downstream from a vertical bend, the path should be in the horizontal plane that is between one-half and two thirds of the distance up the vertical axis from the bottom of the duct for upward flow in the vertical

section, and is between one-half and one-third of the distance up the vertical axis from the bottom of the duct for downward flow (Figure 302.7).

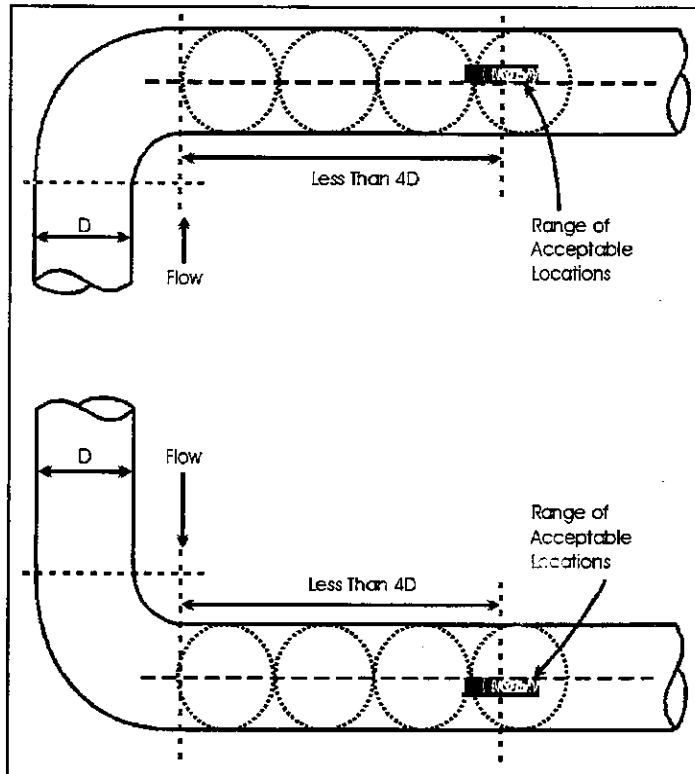


Figure 302.7 Transmissometer Location Less Than Four Diameters Downstream of a Vertical Bend in a Horizontal Stack

Alternative locations and measurement paths may be selected if necessary (i.e. if there are no locations available that meet the requirements and are accessible). For any alternative location or path it must be demonstrated that the average opacity measured is equivalent to the opacity measured at a location or path meeting the requirements. The alternate location is equivalent if the measured opacity is within $\pm 10\%$ of the opacity at a location meeting the requirements; or the difference between the two opacity readings is less than 2% opacity.

302.3 FLOW RATE MONITOR GUIDELINES

Flow rate (velocity) monitors consist of three principle types of instruments: differential pressure sensors, thermal sensors, and acoustic sensors. See Section

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Continuous
Emission
Monitoring

203 of this manual for a more in-depth discussion of the theory and design of these instruments.

302.3.1 Differential Pressure Flow Rate Sensors

Differential pressure sensors are the simplest velocity sensors. These devices measure the pressure difference between an upstream directed (impact) and downstream directed (static) pressure sensor. These can consist of a pitot tube, such as used in source testing, affixed at a representative position in the stack. Or an annubar with multiple pressure taps to obtain an average velocity. Since they must face directly into the gas flow, differential pressure type velocity sensors can be quite sensitive to position and orientation in the stack.

302.3.2 Thermal Flow Rate Sensors

Thermal velocity sensing systems differ from differential pressure-type instruments in that they measure the mass flow rate, not volumetric flow. Thermal sensors give a mass flow of stack gas per unit time (e.g. kg/hr) output.

The sensors (Figure 302.8) measure the rate at which the flowing stack gases remove heat (H) from a heated probe. A second, unheated, probe measures the stack temperature (T_s). The amount of heat (electrical current applied) required to maintain the heated probe at its reference temperature (T_v) is an indication of the flow rate. The cooling rate of the heated sensor is dependent on the thermal conductivity of the stack gas (a function of the gas viscosity and specific heat) in addition to the gas flow. These sensors can give variant results if the composition of the stack gases changes (possibly through a change in process parameters or rate).

While these sensors are sensitive to the direction of flow in the stack (cyclonic, etc.), they are not sensitive to the pressure errors seen in differential pressure-type instruments.^{2,3}

Several sensors can be arrayed across the stack and averaged to give an average velocity. These sensors are usually placed according to Reference Method 1

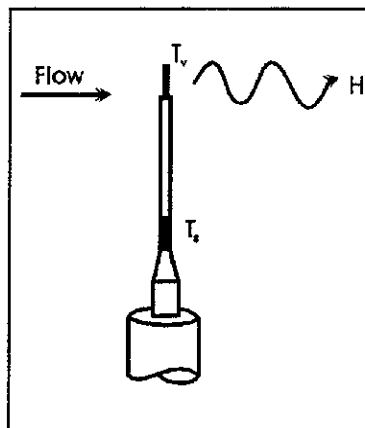


Figure 302.8 Thermal-Type Velocity Sensor

Pitot Tube

Annubar

Heat Loss

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Timed Sound Pulses

sampling points. The individual sensors can also be read to give point specific velocity data which will describe flow stratification in the stack.

302.3.3 Acoustic Flow Rate Sensors

Acoustic velocimetry measures the time it takes a sound pulse to travel with and against the flow.^{2,3} These units are mounted at an angle (usually approximately 45°, Figure 302.9). The angle α between the measurement path and the flow must be known for the calculations to be accurately conducted. Improper mounting or off-axial flow can cause flow rate inaccuracies.

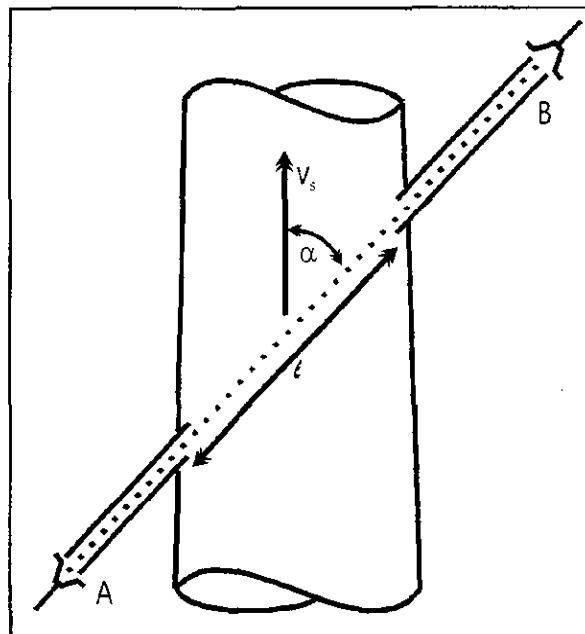


Figure 302.9 Acoustic Velocimetry

A zero reference can be readily calculated by substituting the downstream pulse time for the upstream pulse time. This should result in $t_A = t_B$ and $v_s = 0$. If this relationship does not exist, and the monitor is operating properly, a possible non-streamlined flow error exists. A correction factor can then be inserted into the calculations if the flow (and non-streamlined property) is constant.

302.4 ORIENTATION

Point monitors, either in-situ or extractive, are essentially insensitive to the orientation of the sampling probe to the flow of stack gases (except differential pressure monitors for velocity),³ although it is important that the measurement point is representative. However, for path type in-situ monitors the orientation can make a great difference.

In Section 302.2 the orientation of transmissometers for opacity measurements was discussed. Since opacity is the measurement of the scattering of light by particles, which have inertia, the orientation, especially in relation to bends in the

duct or stack, is very important. In addition, the orientation in a vertical plane can affect the pathlength.

The orientation of rate (velocity) monitors is also very important.^{2,3} We will use a differential pressure instrument as an example. These devices include the simple pitot tube (such as used in source testing) or an annubar. A number of conclusions can be drawn from this discussion, extending its relevancy to opacity, particulate, and gas monitoring. Many of the flow principles will be important to installing almost any type of monitor.

The orientation of the sensor in the stack must be coordinated with both the axis of the stack and the direction of flow of the gases.⁵ If cyclonic, or other non-axial flow, exists it must be determined and either corrected (preferred) or accounted for in calculations.

The two principle misalignment errors are rotational and pivotal (Figure 302.10). Rotational, Case A, errors are caused by not maintaining the face opening planes of the sensor perpendicular to the axial flow in the stack. The pivotal,

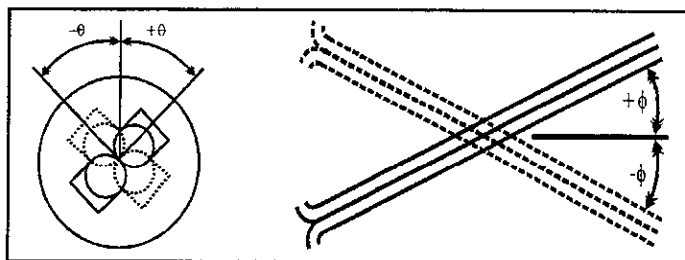


Figure 302.10 Velocity Monitor Sensor Misalignment: Case A (Rotational, Left), Case B (Pivotal, Right)

Case B, error can be caused by vertical misalignment of the sensor in the stack or by using an overly long or unsupported probe which has a tendency to sag, especially under stack heat.

From Figure 302.11 it is obvious that misalignment (rotational, Case A) of up to 50° will result in less than a 5% error in the velocity. It is also obvious that, contrary to popular opinion, the alignment that gives the highest reading does not indicate the true direction of flow. To determine the direction of flow, the sensor must be turned 90° to the flow; the alignment that yields a zero velocity pressure is the angle that indicates the direction of flow.

Figure 302.11 also indicates that more significant, and asymmetrical, errors occur with pivotal (Case B) misalignment. These errors are much greater magnitude than Case A errors. If the differential pressure sensor is pointed into the flow, the

**Rotational
Pivotal**

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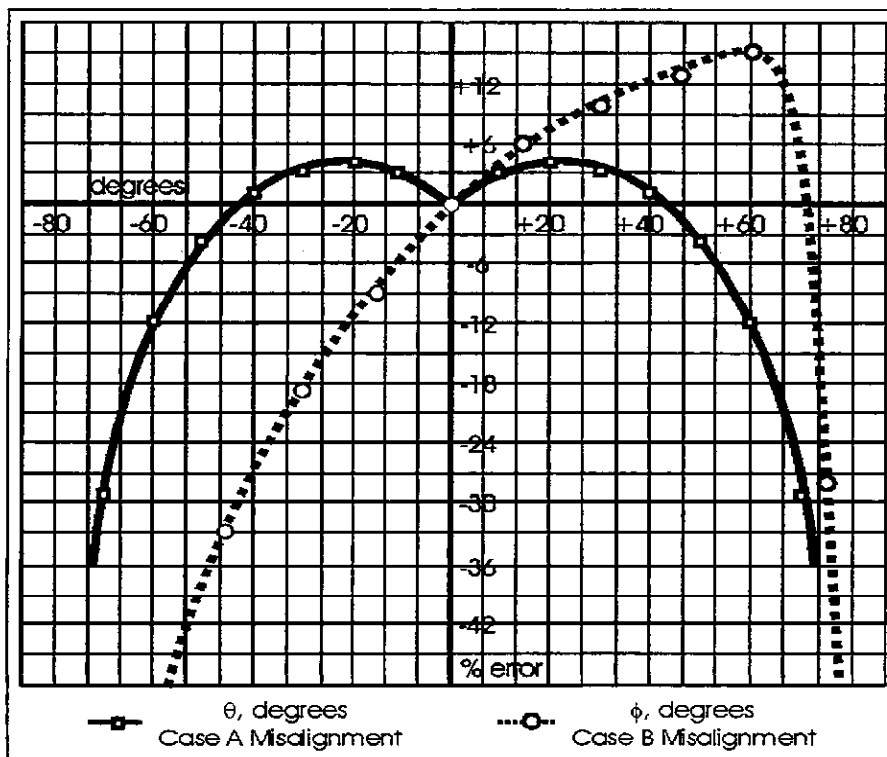


Figure 302.11 Velocity Errors From Sensor Misalignment⁵

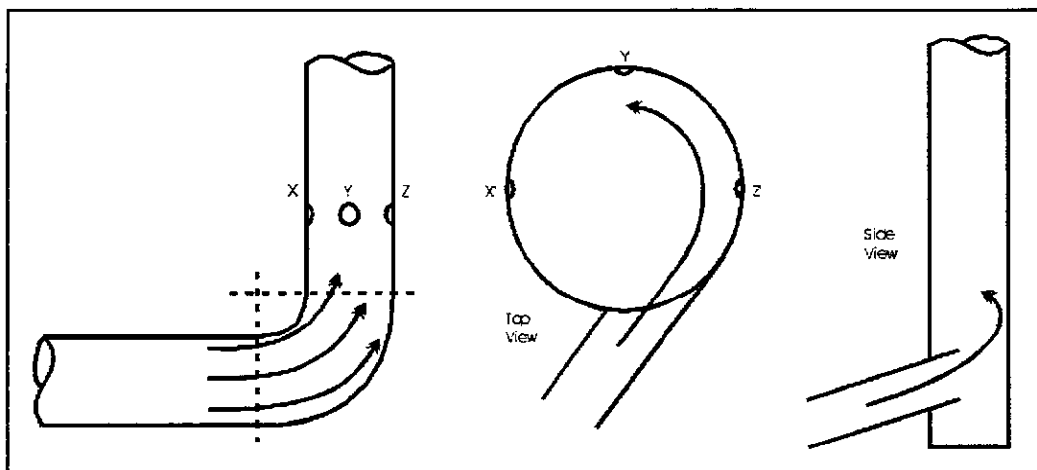


Figure 302.12 Flow After Misalignment Inducing Events: After a Bend or Elbow (left), After Tangential Inlet to Stack (center and right)⁵

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velocities measured are generally too high until approximately 60° , at which point an abrupt change to negative errors occurs. When the sensor is pointed away from the flow, the velocities are generally too low.

The combined error, if both Case A and Case B misalignments exist, is approximately the sum of the two individual errors.

Proper placement and alignment of the sensor in the stack does not necessarily mean that the sensor is properly aligned to the flow. The further the monitoring location is from any flow perturbations (bends in the duct/stack, etc.), the more likely it is that the flow will be properly aligned. However, before a monitoring location is selected the stack flow should be checked for non-streamlined flow.

After a bend or elbow in a duct or stack (Figure 302.12), the most common flow streamlining error, both Case A (rotational) and Case B (pivotal) errors can exist, depending on which port (X, Y, or Z) is being used. Port Y will give Case A errors (Figure 302.13). Port X will give errors corresponding to the left half of the Case B plot in Figure 302.13, while Port Z will give errors corresponding to

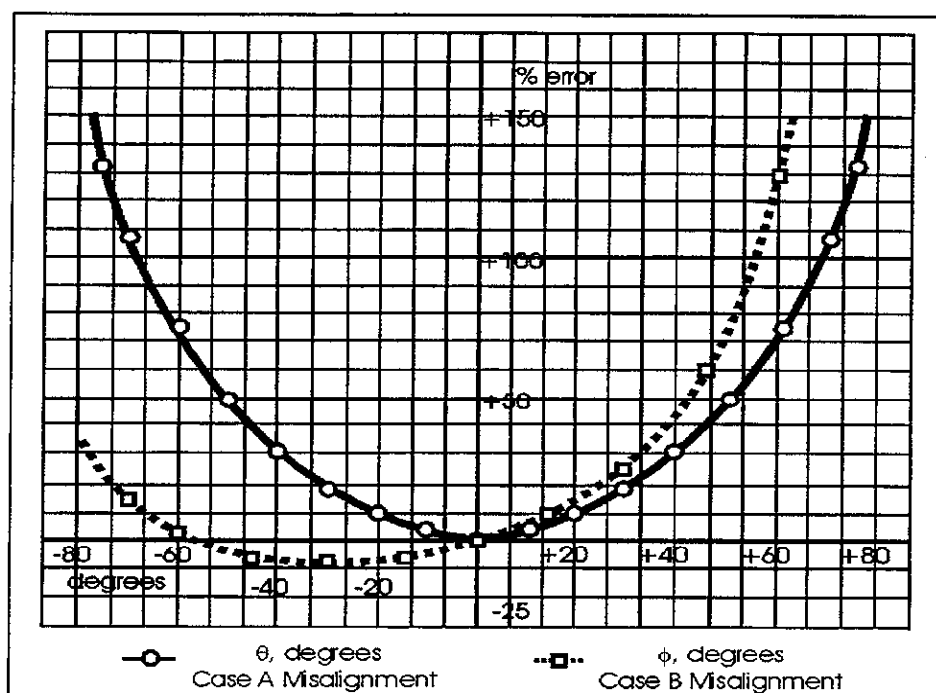


Figure 302.13 Velocity Errors From Flow Misalignment⁵

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the right half of the Case B plot in Figure 302.13. Port X is the only port which gives velocity readings close to the upward velocity vector.

The second important case of non-streamlined flow is tangential or cyclonic flow. This normally occurs after a cyclone or when the stack breach is tangential rather than straight into the stack (Figure 302.12). There are only two velocity vectors, axial and tangential, so that, regardless of which port is used, the error always corresponds to the Case B curve of Figure 302.13. The larger the tangential vector, the larger the error will be.

The foregoing discussion of the orientation of the monitor path also pertains to particulate monitoring. Both in particulate monitoring per se and in opacity monitoring, streamlining of the flow is important in whether the pollutant concentrations are stratified across the stack. The flow errors can also play an important role in the rate monitoring required to determine mass emission rates. Recall from earlier that Part 75 acid rain sources require that the emissions be reported on a mass emission basis. In gas monitoring, flow stratification can lead to stratification of the concentrations of the pollutants as well.

303 CALIBRATIONS

All monitors must provide a means of calibration and of verifying the calibration. Owners and operators of continuous emission monitoring systems must check the zero (or low-level value between 0 and 20 percent of span value) and span (50 to 100 percent of span value) calibration drifts at least once daily.^{6,7} If either the zero (or low-level) or high-level calibration drift exceeds twice the applicable drift specification (Table 303.1) for five consecutive daily periods the CEM system is deemed to be out-of-control.⁸ Also, if any zero (or low-level) or high-level calibration drift result exceeds four times the applicable drift specification during any calibration drift check the CEM system is also deemed to be out-of-control. If the CEM system is out-of-control, necessary corrective action must be taken and the calibration drift checks repeated.

In a well operating system, the system operator should not have to re-zero or recalibrate the system every 24 hours when the values are checked. If continual drift occurs, even if less than that requiring corrective action, the operator should examine the CEM and correct the causes of the drift. This should be addressed as part of the instrument QA plan.

**Daily Zero
and Span
Checks**

Adjustments

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Table 303.1 Calibration Drift Performance Specifications

PS	Parameter	Calibration Drift
1	Opacity	≤2% opacity
2	SO ₂ , NO _x	2.5% of span
3	O ₂ , CO ₂	0.5% O ₂ or CO ₂
4	CO	5% of span for 6 of 7 test days
5	TRS	5% of span for 6 of 7 test days
6	Rate (flow)	3% of 1.25 times the average potential value
	Rate (temperature)	1.5% of 1.25 times the average potential value
7	H ₂ S	5% of span for 6 of 7 days

However, the operator should not "chase the noise" in the system. Normally the system should not be adjusted until the total drift has exceeded twice the performance specification value. For example, for an SO₂ system, the drift specification is 2.5% of span. The system should be adjusted when the total drift reaches 5% of span. If the span value is 500 ppm, drift adjustments should be made when the drift reaches 25 ppm (500 times 0.025 x 2).

There are several types of calibration check procedures that can be used. If the system allows, the calibration gas should be injected outside the particulate filter to flood an entrance cavity of the sampling probe. Calibration drift checks performed at the back of the instrument are unacceptable. The specific

procedures to conduct the calibration drift test on a specific piece of equipment are delineated in the monitor operating instructions from the manufacturer.

- **Simulated Zero and Span** (Figure 301.5) - This system is used by transmissometers and some other in-situ monitors to simulate a zero reading by placing a mirror at the exit of the transmissometer window to reflect the light beam back without going through the stack and an upscale reading by placing a neutral density filter in the light beam with the zero mirror blocking the beam.
- **Internal Gas Cell** (Figure 303.1) - The internal gas cell is similar to the simulated zero and upscale system. It is primarily used for in-situ gas monitor systems. A zero mirror reflects the light beam back without entering the stack.

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Zero air and calibration gases flow through a flow-through gas cell to generate an up-scale reading.

Cylinder gases must be high concentrations (percent level rather than part per million level) to obtain an optical depth equivalent to a pollutant up-scale value at the stack pathlength. These systems are useful for daily spans of NSPS (Part 60) sources. However, since protocol gases are not certified at the concentrations required, these instruments cannot be used for Part 75 sources or for Part 60 source quarterly tests.

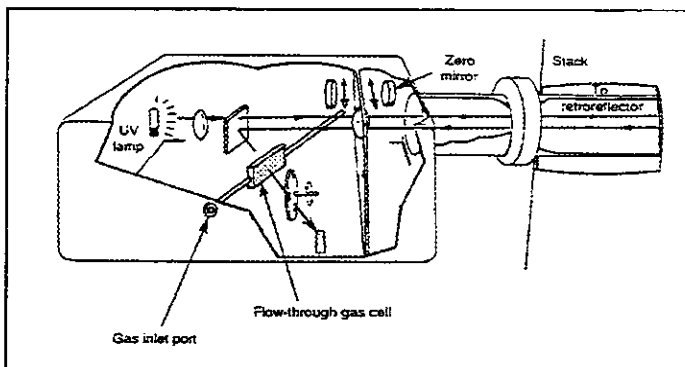


Figure 303.1 Flow Through Internal Gas Cell Calibrations

In-Situ Audits With Calibration Gases

- **External Gas Cells** (Figure 303.2) - As an audit device of path in-situ monitors, a flow-through gas cell is attached to the analyzer in place of the probe. The calibration gas (corrected for the proper optical depth) is passed through the cell. With the proper configuration and gas conditioning system an in-situ monitor can be converted into an extractive monitoring system by the permanent attachment of a flow-through external cell.

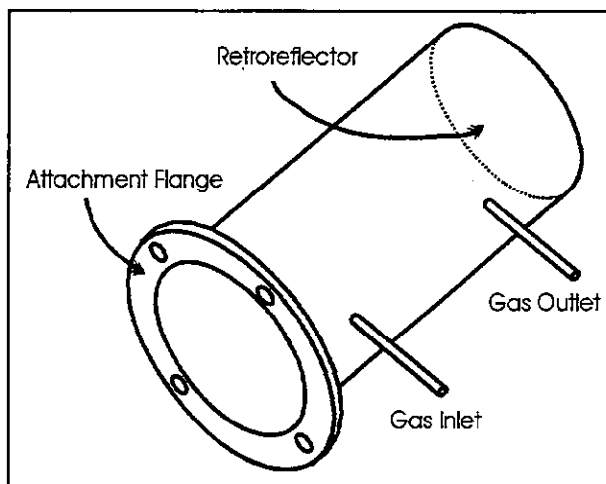


Figure 303.2 Flow Through External Gas Cell Calibrations and Audits

External gas cells can also be sealed cells, to be inserted into the analysis light beam. These cells can provide a performance check; however, their values are generally not certified and therefore have limited use in calibrations and audits.

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- **Injecting Calibration Gases** (Figure 303.3) -

This is the most widely used calibration and audit method for extractive and point in-situ monitors. Calibration gases are injected into the monitoring system at the sampling probe. The best injection point for the gas is outside the course filter within the particulate shield. If necessary, the calibration gas can be injected into the sample line immediately after the probe (Figure 303.4), however, outside the course filter is far better. The sample line is often coiled inside the probe to allow the calibration gas to heat up to stack temperature before entering the cavity. Excess gas is vented into the stack as the monitoring system withdraws sample gas through the probe at its normal rate. If any interference is caused by accumulated particulate on the course filter, this procedure will detect it.

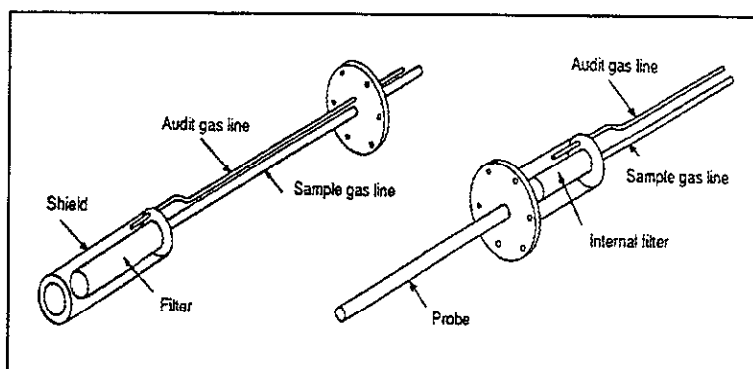


Figure 303.3 Extractive Probe Calibration and Audit Gas Injection

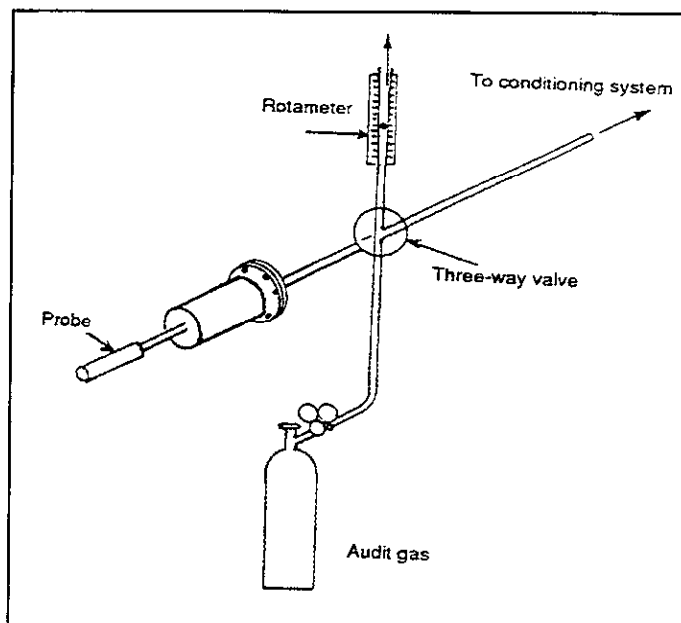


Figure 303.4 Alternate Calibration and Audit Gas Injection Method

Extractive System Audits

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Zero and Span

303.1 TRANSMISSOMETER CALIBRATIONS

Each transmissometer used to monitor the opacity of emissions must include a system for simulating a zero (or a low-level no greater than 10%) opacity and an upscale (greater than or equal to the applicable standard, but less than or equal to one half the instrument span value) opacity value. Simulated zero and upscale procedures are used since most instruments cannot actually produce a zero or upscale calibration value across the stack while the source is in operation. The simulated zero and upscale checks must be conducted at least once every 24 hours. During the initial PSI design certification tests, a calibration error test using three certified neutral density filters must be conducted (see Section 401.2). The initial calibration error test may be conducted at the manufacturer's facility or at the source facility.

During the initial testing of the transmissometer the sum of the absolute value of the mean and the absolute value of the confidence coefficient is reported as the calibration drift. During routine operation the daily drift should be recorded and checked against the performance standard (Table 303.1). Adjustments and cleaning must be performed when the accumulated zero calibration or upscale calibration drift exceeds the 24 hour drift specification ($\pm 2\%$ opacity). If any out-of-control periods occur, corrective action must be taken and the drift tests repeated.

303.1.1 Simulated Zero and Upscale Calibration Drift Procedure

To provide the simulated zero opacity on double pass instruments, the most common practice is to insert a zero mirror at the exit of the transmissometer window (Figure 301.5). This mirror provides a simulated zero by returning the light to the detector without crossing the stack. For the upscale calibration, a neutral density filter is placed in the light path with the zero mirror blocking the beam from the stack.

303.1.2 Zero Drift Test

At the outset, the initial simulated zero and upscale opacity readings should be recorded. After each 24 hour interval, check and record the final zero reading before any optional or required cleaning and adjustment. Any time adjustment or cleaning is conducted, a zero check should be done before the monitor is serviced. If no adjustments are made after the zero check, record the zero reading as the initial zero value for the next 24 hour period. If the monitor is cleaned or

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adjusted, record the zero reading after servicing as the initial zero value for the next 24 hour period. If the instrument has an automatic zero compensation feature for dirt accumulation on exposed lenses, and the zero value cannot be measured before compensation is entered, then record the amount of automatic zero compensation (as percent opacity) for the final zero reading of each 24 hour period.

From the difference between the initial and final zero readings, calculate the zero drift for each 24 hour period. The zero can be adjusted before reading the upscale value since the zero drift is subtracted from the calibration drift in the calculations; adjusting it before the upscale reading physically rather than mathematically corrects the drift.

24 Hour Zero Drift

303.1.3 Calibration Drift Test

At each 24 hour interval, after the zero calibration value has been checked and any optional or required adjustments have been made, check and record the simulated upscale calibration value. A neutral density filter is used to obtain the required obscuration of the light beam. If no further adjustments are made to the calibration system at this time, record the final upscale value as the initial value for the next 24 hour interval. If an instrument span adjustment is made, record the upscale value after adjustment as the next initial value. From the difference between the initial and final upscale readings, calculate the upscale calibration drift.

24 Hour Calibration Drift

For the calibration drift test, the filter does not have to be certified. However, the value must be stable and should be periodically checked. Filters used for a calibration error test must be certified every three months.

303.2 EXTRACTIVE GAS MONITOR CALIBRATIONS

It is important that the calibration system include the entire monitoring system.⁸ There are a number of sources of error in the system, such as tubing leaks or particulate accumulations, that an instrument back calibration would not catch. Calibrations at the back of the instrument are not acceptable, although injection of calibration gas directly into the analyzer can be useful in troubleshooting. Specific test procedures are discussed in Chapter 400 - Testing and Certification.

Calibrate the Entire CEM System

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303.2.1 Source Level Extractive Systems

If possible, the calibration gas should be injected outside the coarse filter; either between the filter and the shield or within the chamber of an internal filter (Figure 303.3). The excess gas then is exhausted into the stack. An acceptable (although considerably less desirable) alternate point to inject the calibration gas is at the exit of the probe (Figure 303.4), with the excess gas exiting through a rotameter (to confirm that the system is being flooded with gas). The analyzer should be calibrated at the same gas flow rate, pressure, and temperature that are used when operating.

303.2.2 Dilution Extractive Systems

It is particularly important that a dilution probe be calibrated at stack conditions. The sonic orifice used in a dilution probe is very sensitive to stack pressure and particulate plugging. Also, each orifice will be slightly different, and responds slightly differently to changing temperature and pressure of the stack. The system must be recalibrated after any time a dilution probe is serviced.

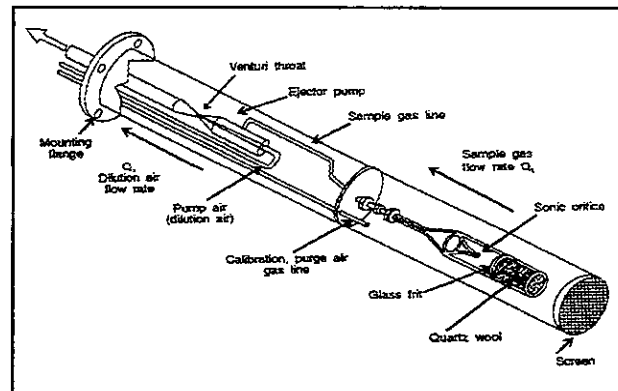


Figure 303.5 Dilution Extractive Probe Calibrations

The entire dilution system must be calibrated, including the probe (Figure 303.5). The alternate procedure (Figure 303.4) is unacceptable.

303.3 IN-SITU MONITORS

Calibration of point in-situ monitors closely mirrors the calibration of source level extractive systems, while calibration of path in-situ systems is similar to the calibration of transmissometers.

303.3.1 Point In-Situ Systems

In point in-situ systems, the calibration gas floods the analysis chamber, forcing out the stack gases (Figure 303.6 and Figure 303.7). Excess calibration gas will

pass through the filter and out the stack. The calibration gas input line shown in Figure 303.6 is coiled around the probe; this is to equilibrate the calibration gas temperature to the stack temperature.

It is possible to over-pressurize the analysis chamber due to particulate buildup on the filter. At higher pressure the concentration of the calibration gas will be higher than the true concentration and will lead to erroneous calibration checks (more gas molecules will be in the beam path than expected). Particulate buildup is indicated by checking the pressure of the calibration gas during the calibration and by slower than normal return to stack values after a calibration.

303.3.2 Double Pass Path In-Situ Systems

Double pass path in-situ CEM systems often use flow-through gas cells (Figure 303.1) to conduct zero and span calibration checks. The procedure for this is similar to the simulated zero and span for a transmissometer. While flowing zero gas (zero to 20% of span) through the cell a zero mirror blocks the path through the stack and reflects the analysis light beam back to the detector without crossing the stack. For the upscale span, a calibration gas at a concentration to give a 50 to 100% span response is flowed through the gas cell.

The upscale span gas must be corrected for the pathlength, resulting in very high concentration gases being required. For example: if a monitor's span value is 600 ppm SO₂ in a 10 meter stack the optical depth of the stack is $600 \times 10 = 6000$

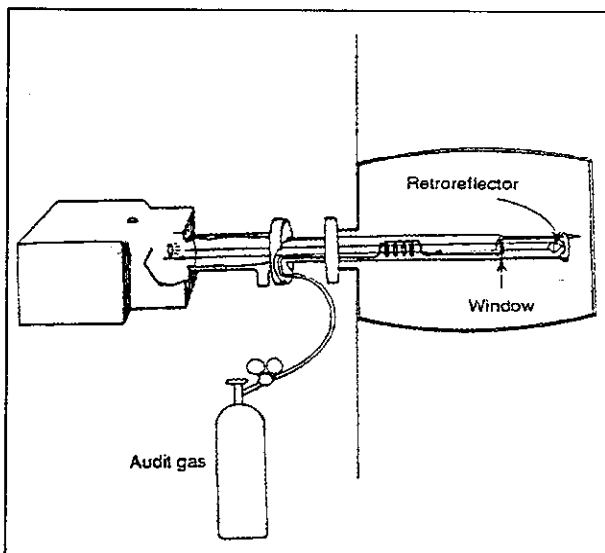


Figure 303.6 Calibration Check of Point In-situ Analyzer

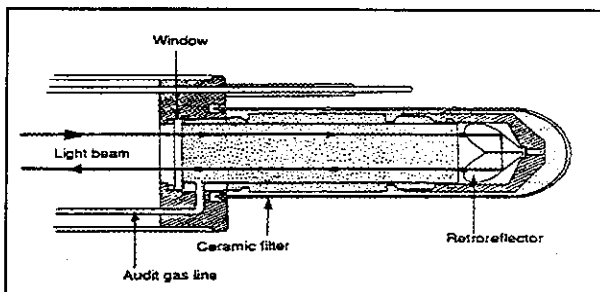


Figure 303.7 Magnified View of a Probe Calibration for a Point In-situ Analyzer

Flow-
Through
Gas Cell

Optical Depth

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ppm-m. If the flow-through gas cell is 1 cm (0.01 m), a cylinder gas would have to be $6000 \text{ ppm-m} / 0.01 \text{ m} = 600,000 \text{ ppm}$ (60%) for an equivalent optical depth. NIST traceable Protocol gases are not certified at that concentration. This procedure is acceptable for the daily zero/span calibration checks for NSPS (Part 60) sources (and may be acceptable for state and district mandated monitoring depending on the state and district requirements). The requirements of NSPS for the daily calibration check do not require that certified gases be used. Acid rain (Part 75) monitoring, however, requires that certified gases be used daily; therefore, the flow-through cells are not acceptable for Part 75 sources. Another method (such as extractive or dilution systems) works better in these cases.

303.3.3 Single Pass Path In-Situ Systems

Single pass path in-situ CEM systems are extremely difficult to conduct calibration drift checks on. Some means of excluding or bypassing the stack gases is required. Several ways of providing for calibration drift checks have been devised, however, none are as good as using a double pass or extractive instrument. One means is with a zero pipe that closes for the zeros and calibrations and opens to monitor the stack gases. Diversion units that remove a sample of stack gases from the stack, analyze them and return them to the stack have also been used with some success. A third means of using a single pass system is by using fiber-optic cables to carry the light around the stack to the detector.

304 QUALITY ASSURANCE

A quality assurance (QA) program is a management program designed to ensure that quality control (QC) activities are being performed. A comprehensive QA plan will specify the routine and emergency maintenance and repair procedures to ensure reliable operation of the continuous emission monitoring system and that the data generated is both accurate and precise as well as testing procedures and protocols.

A QA plan will address the six key principles of Who, What, Where, When, Why, and How.⁹ The most important are Who, What, and How, although all six principles are important. The plan should specify Who is in charge of What part of the program and How, in detail, the work will be accomplished.

Knowing the Why of data collecting is critical to the success of any project. Data must be collected with a purpose, otherwise incomplete and inaccurate data

Zero Pipe
Diversion

Fiber Optic

Who
What
When
Where
Why
How

may be collected. Different purposes require different data collection plans. The QA planning documents must clearly state the purposes behind the data collected so that both current and future users understand the data and its limitations. A simple organization chart greatly simplifies the planning procedure. If the relationships are difficult to draw, they will be even more difficult to execute.

Examples of typical QA planning documents include the following:

- Data quality objectives reports
- Work or test plans
- Quality assurance plans
- Site selection, sampling, and analytical procedures
- Standard operating procedures (SOPs)
- Data handling protocols
- Corrective action plans

A written QA plan is required by Appendix F of 40 CFR 60⁸ and Appendix B of 40 CFR 75.⁷ Although Appendix F applies directly only to NSPS sources that require CEM systems for compliance purposes, many states and districts have adopted Appendix F specifications, referenced them in their regulations, or have incorporated them through permit processes. Appendix F, therefore, has been applied to a much wider extent than originally intended.

304.1 QUALITY ASSURANCE FRAMEWORK

Figure 304.1 illustrates a coherent QA program. Quality Control activities begin before the system is purchased and continue for the life of the system. Three principal (although not mutually exclusive) phases of QC activities are purchasing the system and spare parts, installing and certifying the system, and providing for continuous operation. In each phase, as well as all activities associated with QC for the CEM system, recordkeeping represents an important aspect of QA.

**Purchasing,
Installation and
Certification,
Operation**

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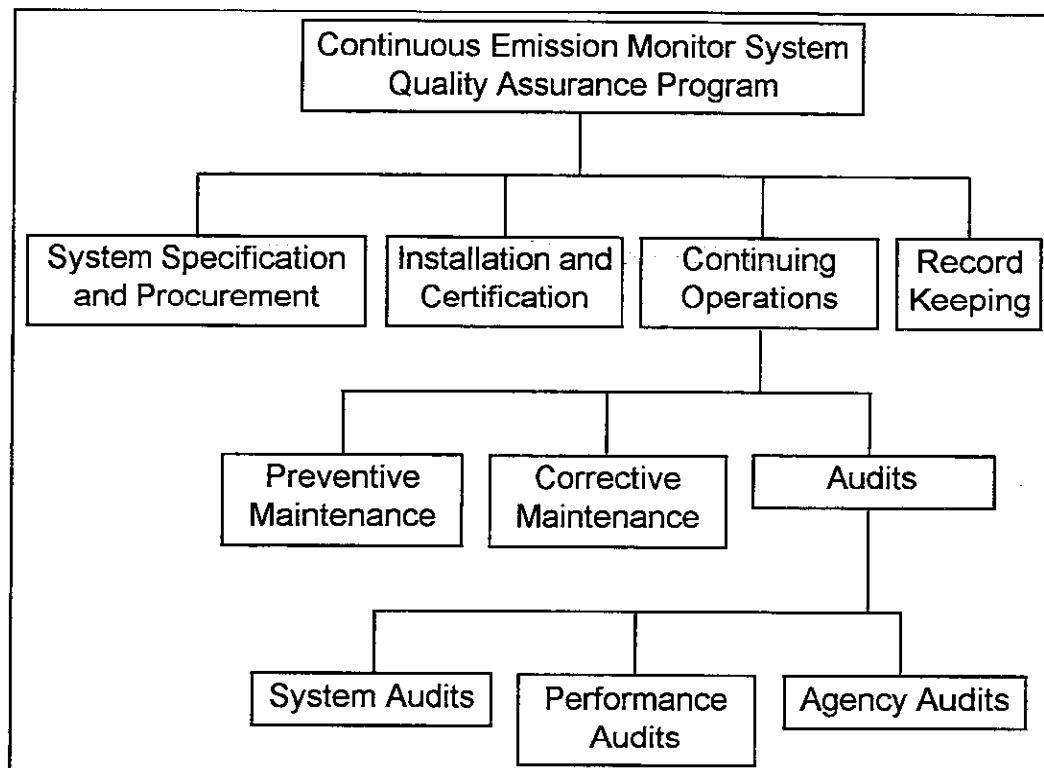


Figure 304.1 Framework for Quality Assurance Activities

304.2 SYSTEM SPECIFICATION AND PROCUREMENT

An orderly procedure for system selection, procurement, and spare parts inventory is essential to selecting the proper system and keeping it operating up to its maximum capabilities. A source that is required to install a CEM system will want to install the best system at the best cost. In evaluating what constitutes the best system, installation site requirements, flue gas conditions, and other plant-specific factors are important. In addition, manpower and data processing availability and requirements of the system must be factors in the decision. Purchasing an initially low cost system may be the long term expensive option when all factors are considered. Excessive maintenance and repair costs and time demands could doom the system to poor quality operation.

304.2.1 Needs Evaluation and System Selection

The initial evaluation of the match between the facility's CEM needs and available system designs is critical in selecting the proper system for the application in

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question. Once the proper system has been selected, the remaining QA factors, both at the initial stage and for years to come, will be clarified and potential problems minimized.

The first information needed is an evaluation of the purposes of monitoring. The regulations and permit provisions requiring the CEM can greatly influence the system design requirements.

An additional part of the first stage of CEM system selection is to evaluate the process and stack parameters being monitored. Estimates of the expected pollutant concentration, moisture content, velocity, etc. (probably available in the permit application package) are important in establishing the scale of the monitor. Also, the stack temperature, vibration, and environmental conditions can be important parameters in the decision. If the stack has a vibration, an in-situ monitor may not operate reliably. If the vibration is significant, as much equipment as possible should be off the stack; for example, in a CEM shelter at the base of the stack. This would indicate an extractive system, either source level extractive or a dilution system. If the vibration is severe, it may be wise to have the dilution occurring outside of the stack, usually in the CEM shelter.

The decision to use an in-situ or extractive system may be dependent on the pollutant being monitored (opacity transmissometers are inherently in-situ instruments, etc.), stack conditions, or on the preferences of the facility staff. In many larger companies some degree of consistency throughout the company's sources requiring monitors is preferred. Standardization of monitor types, vendor, etc. can help assure more consistent maintenance and a better spare parts supply.

After narrowing the list of possible monitors and vendors, a more in-depth examination of the CEM system designs is the next step in the decision. A bidding package containing information about the facility and the specifications for the CEM system should be sent to all potential vendors. If similar sources exist, a visit to those facilities may help illustrate the monitoring problems encountered with that system and how those problems were solved. Vendors may be willing to conduct a runoff between systems offered; especially if several units are to be purchased for company-wide application.

304.2.2 CEM System Technical Specification Writing

A complete and thorough set of specifications is crucial in procuring the CEM and the continuing procurement of spare parts. Good specifications provide the

Purpose

Process and Stack Parameters

In-Situ or Extractive

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basis for a purchaser to obtain the desired CEM system and for the vendor to provide the optimum equipment and service. Throughout the process records of vendor literature, phone logs, meeting notes, etc. provide a complete record of the process. Confusion, poor operation, and law suits can result if the system is designed to inadequate specifications.

After receipt of the technical specifications, the vendors will prepare proposals and bid on the project. The bids can then be evaluated for technical merits and costs.

A typical CEM system specification will incorporate the following sections:

Purpose

A statement describing the facility, regulations, and permit requirements.

Scope of Work

An outline of hardware and services to be provided by the vendor. This section can contain the basic system design, data acquisition and control requirements, and other requirements of the vendor. Vendor furnished services can include engineering services (can be minimal services to full design and engineering of a turnkey system), installation, startup, and testing.

Equipment and Services Provided by Others

A listing of equipment and services that the vendor is not expected to supply. This may include existing equipment (existing monitoring systems, elevators, catwalks, ports, platforms, electrical supplies, etc.), calibration gases, etc. It also may include services supplied by other contractors or by facility personnel such as system installation, wiring, testing and certification, etc.

Description of Operating Conditions

A description of the environment and stack gas conditions at the sampling location. Information about the flue gas characteristics; such as moisture content, velocity, temperature, composition, and concentration of pollutants is critical for the vendor to design a system that will operate in the required conditions. If these items are unknown the vendor cannot provide the system needed.

Design Criteria and Construction

A detailed description of the system on which the bid is to be prepared. The design criteria must be sufficient to provide the vendor with a regulatory and operational understanding of the system requirements. These requirements include adherence to standards, codes, and regulations including instrument range, drift, and response time. The design requirements also can include specifications for sample conditioning and interfacing with existing plant systems, as well as data acquisition and reporting formats.

Often this is the largest section of the specifications package. However, vendors should be given enough leeway in the specifications to design a system using their best knowledge and equipment. If the specifications are too stringent vendors may refuse to bid or submit an alternate system based on their experience, rather than the specification requirements.

Vendor Furnished Services

A listing and description of services desired from the vendor. These may include: total project management, installation, training, and ongoing maintenance services.

Certification and Testing Guarantees

A listing of certification guarantees and warranties expected from the vendor. These might include factory checkout and certification provisions, performance test guarantees, and system availability requirements.

Equipment Delivery Requirements

A statement of progress report requirements, delivery dates, and shipping requirements.

Engineering Data and Documentation

A listing of required system documentation items to be supplied with the system. This should include system schematics and wiring diagrams, operating manuals, maintenance instructions, and data acquisition system (DAS) operating instructions and documentation. Sufficient documentation should accompany delivery

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of the CEM system so that the facility can fully operate and maintain the system. The facility may also ask that the vendor supply training for the CEM operators.

304.3 INSTALLATION AND CERTIFICATION

Quality assurance and quality control plans should be included as part of the performance specification test protocol. The performance specification test is a comparison test between the CEM and a reference method. In this procedure it has been determined that the EPA reference methods can be regarded as a standard against which the CEM can be tested.

304.3.1 Test Protocol - Performance Specification Test

Addressing QA and QC in a test protocol can assist the source tester in thinking how the test will be organized and conducted. A clear and concise test protocol with integral QA/QC provisions will also clarify issues of responsibility, sample custody, calibration, and sample collection. The final details of the test protocol should be discussed in a pretest conference with all parties well before the test date.

The test protocol should contain the following information:

Title Page

Table of Contents

The table of contents should list contents, figures, tables, and appendixes with page numbers.

Project Description

In a summary of the test program identify:

- Responsible groups and organizations
- Overall purpose of the test
- Regulations and permit provisions addressed by the test
- Plant name, location, industry type, process of interest, emission point to be tested
- Pollutants to be tested
- Dates of tests

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Project Organization and Responsibility

To avoid confusion during the test, the role of the agency observer, plant engineers, plant environmental specialists, source test team leader, and source test personnel should be clearly stated. An organizational chart with names, telephone numbers, and lines of communication can facilitate the roles.

Source Description

An important part of the test protocol, and any QA plan, is an understanding, by everyone involved, of the process in question. This section should have a complete description of the process. The discussion should include the unit and equipment operations that might affect emissions, testing, or the test results; e.g. batch operation, high moisture, high temperature, the presence of interfering compounds, and the plant schedule.

Included in the process description should be a description of the air pollution control systems and their operation and the normal operating ranges of key parameters. The key operating parameters include: standard operating ranges, production rates, and feed rates. There also should be a process flow diagram and a facility equipment layout diagram with the emission points clearly indicated.

An important part of the facility layout and process flow diagram is an indication of the sampling locations. Indicated on the diagram should be the duct diameter, direction of flow of stack gases, dimensions to the nearest upstream and downstream disturbances, location and configuration of the sampling ports, nipple length, and the port diameter. This layout should be evaluated to be sure it meets the EPA criteria (i.e. Reference Method 1). Any nonstandard traverse information should be noted, especially if the stack is not a circular or rectangular duct.

Sampling and Analytical Procedures

Test and analytical procedures should be outlined in this section. Usually the permit for the facility to be tested or a regulation covering the facility (i.e. NSPS, etc.) will dictate the test and analysis methods to be used.

If U.S.EPA reference methods are to be used for the relative accuracy test, the QC activities in Volume III of the *EPA Quality Assurance Handbook*¹⁰ should be referenced in the plan. Other QC procedures can also be incorporated in the

Unit and Controls

Key Parameters

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Test Methods

plan. For example, if California testing methods are to be used, the QC procedures should be tailored for those methods. If a non-EPA method (or a method not specified in the permit) is to be used in place of an EPA or other approved method, or the approved method modified, the reasons for the method change must be given. In such a case the entire test method should be given in the test protocol. Sufficient detail must be given so the proposed method can be evaluated in relation to the approved method. Sufficient time must be allowed for the evaluation, in which case, the test protocol should be submitted earlier than required by the permit provisions or regulations.

Conditions for representativeness of plant load conditions, sampling conditions, and procedures for treating data in case of plant shutdown should also be addressed. The reference method and CEM data should be taken at the same time and compared over the same period. Corrections will be necessary for CEM measurement times for systems that have long sampling lines or slow response times.

Time Shared CEMs

Time share CEM systems present a significant problem in comparing measurements. If a CEM system monitors a source for five minutes over a 15 minute period, the data might not be comparable to that obtained by a reference method measuring the source emissions over a 20 minute period.

Soot Blowing

If soot blowing occurs at the facility, it should be included in the test. Specific times of soot blowing, areas of the boiler blown, etc. should be discussed in the test protocol and recorded in the test results. These issues should be resolved at the pretest meeting.

Operating Conditions

During the testing the plant should operate under normal conditions. Performance specifications 2 - 7 stipulate that the facility must operate at least 50% or at normal load conditions.

Because of the peculiarities of the relative accuracy test calculations, the higher the reference method test results (within limits of the permit or regulation emission limits) the easier it often is to pass the relative accuracy test. Often, because of the presence of air pollution agency personnel during the test, the plant manager might wish to reduce pollutant emissions to levels lower than normal. Such a practice will make it more difficult to pass the relative accuracy test because of the calculation method. Also, and possibly more importantly, the conditions and procedures during the test may be incorporated into the permit for the facility.

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Reducing emissions for the test may lock the facility into conditions under which they do not wish to operate.

If process stream samples (raw feed materials or fuel, etc.) are to be taken they should also be discussed. This should include a schematic of the sampling locations and a discussion of how and when each sample will be taken. A description of analytical, sampling, or other procedures for obtaining the process stream samples should be given. Why the process samples are to be taken and how they relate to the representativeness of the emission samples should also be discussed.

Process Samples

Sample Identification and Custody

Every sample taken during the test must be uniquely identified. The ID should include the date and time, the name and address of the facility being tested, the name of the person collecting the sample, and a unique sample ID code. In addition, each sample must be accompanied by a chain-of-custody form. Each time the sample changes hands the exchange must be documented by signatures of the person giving and the person receiving the sample. In case of contested results, the possession of the samples must be able to be reconstructed at all times to eliminate the possibility of contamination. This can be very important if the test results become evidence in a legal case.

QA/QC Activities

Quality assurance and quality control are very important to assuring that the installation and certification are done properly. A section of the proposed test protocol and the test report should extensively treat how QA/QC is to be incorporated and provide the results. Quality control activities should be incorporated into all phases of the test procedure: field testing, analysis, data reduction, and reporting. Numerous forms for evaluating EPA test methods are in Volume III of the EPA Quality Assurance Handbook: Stationary Source Specific Methods.¹⁰

EPA QA Handbook, Volume III

Examples of quality control checks are calibrations of instruments, matrix spikes, duplicate analyses, internal standards, blanks, linearity checks, drift checks, response time checks, and system bias checks. Orsat F factor (F_o) calculations are a good means of checking the CO_2 and O_2 CEM readings.

A good technique to follow prior to conducting the relative accuracy test is to compare the calibration gases used to span the CEM system with the Protocol 1 (or other) gases used to calibrate the reference method instrumentation. This

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Test and Laboratory QA

comparison will help to determine systematic errors attributable to the calibration gas values. For Part 60 sources the gases used for calibrations and daily spans of the monitors are not required to be certified. However, for Part 75 sources NIST/EPA approved certified reference materials, NIST traceable reference materials, standard reference materials, or Protocol 1 gases (certified to be within 2% of the concentration specified) are required.

Source testing and laboratory analytical procedures for reference method tests should be conducted only by experienced personnel. Statements of experience or personnel resumes are useful to corroborate this in the project plan. EPA audit samples also should be incorporated with the field samples to estimate sample collection and laboratory analysis accuracy and precision.

304.4 CONTINUING OPERATION

Successful CEM systems are generally associated with an established and followed QA/QC program. Concern for CEM system performance cannot end after the system passes the performance specification test. There must be an ongoing QA/QC program for the life of the monitoring system.

Prior to 1987 the EPA's CEM system requirements focused on PST Procedures. Periods of CEM system downtime and the nature of repairs and adjustments were reported in the quarterly excess emission reports. However, these reports were not always sufficient to ensure that the systems were providing quality data. Appendix F of 40 CFR 60,⁸ promulgated in 1987, did much to rectify the situation. One of the most important features of Appendix F is that it requires the source to develop and implement a QA program. Appendix F currently addresses only gas monitoring systems used for compliance determinations. It will likely be extended to transmissometers in the future. The principal focus of Appendix F is on audits and testing of the monitor. It also requires written procedures for preventive maintenance and corrective action, but does not set out specific requirements.

As a minimum, Appendix F requires written procedures which describe, in detail, complete, step-by-step procedures and operations for the following activities:

- Calibrations
- Calibration drift determination and adjustment
- Data recording, calculations, and reporting
- Accuracy audit procedures including sampling and analysis methods

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- Preventive maintenance (including spare parts inventory)
- Corrective action for malfunctioning CEMs

These activities compose a set of standard operating procedures (SOPs) that are normally incorporated into the QA plan. A QA plan states the source's philosophy and approach to the QA program. This is important because it establishes the implementation procedures for the QC activities.

The EPA has established formats for QA plans. One commonly used format is given in the EPA *Quality Assurance Handbook - Volume I*.⁹ The CEM plan should include discussions of the following topics:

Section I - General Aspects

- QA policy and objectives
- Document control system
- Project description
- Organization and responsibilities
- Facilities and equipment
- Methods and procedures - analysis/data acquisition
- Calibration and QC checks
- Maintenance - preventive/corrective
- Performance audits
- Corrective action program
- Reports

Section II - Standard Operating Procedures

Section III - Appendices

- Operating permit
- Applicable regulations

304.4.1 Standard Operating Procedures

A standard operating procedure (SOP) is written so that the procedure will be performed consistently by everyone, every time. An SOP should be written for any procedure that can affect data quality and is performed repetitively or routinely. Although preparing an SOP requires a significant investment of time and effort, there are important long term benefits. A written SOP can be incorporated into plans, reports, etc. by reference and/or attaching a copy as an appendix. A well written procedure will focus on routine operations, the user then can

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concentrate on nonroutine problem solving. Also, data collected under a documented procedure will have much higher credibility and defensibility.

Few laboratory or field projects can be described completely in just one SOP. Several are usually needed. In general, an SOP for each of several smaller segments is much better, more flexible, and easier to write than one large SOP for an entire operation.

SOP Format

Figure 304.2 shows a suggested format for an SOP, including numerous examples of items that could be included in each section. The examples shown are only a few of the many that could be covered, depending on the particular procedure. Occasionally, deciding whether an item belongs in one section or another can be a problem. The important thing is to put it somewhere, rather than leave it out.

Document Control

As refinements become available, older SOPs will need to be updated to maintain them as state-of-the-art procedures. A tracking system is necessary to ensure that the most current version of the SOP is being used. Typically a document control format block (Figure 304.3) is used, usually placed in the upper right corner of each page. The SOP is given a number, title, revision number (beginning with '0' for the original SOP), and date. As they are updated, individual pages can be replaced with the most current information.

Availability

A complete set of SOPs should be available in the office of the QA manager. All field and laboratory personnel should also have ready access to copies: an SOP is meant to be used, not just written and filed to fulfill a requirement. In some cases, the company procedures may require the operator to read and sign the SOPs. In which case there will usually be a signature and date space included in the document control format block.

304.4.2 Preventive Maintenance

Reliable Equipment

The first principle of preventive maintenance is to buy reliable equipment. Reliable equipment, which does the job right, will require less preventive maintenance and certainly will require less corrective (repair) maintenance. By requiring less maintenance the system will be better able to provide the monitor availability required by many regulations. It also will likely repay the possibly higher initial capital cost by the reduced maintenance costs.

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A. Technical Sections	
Section	Typical Examples
Scope and Application	Overview outlining purpose, range, sensitivity, acceptance criteria
Summary of Method	Overview describing sampling criteria and analytical methods, method and instrumentation detection limits, reasons for deviations from <i>Federal Register</i> methods
Definitions	All acronyms, abbreviations, specialized terms
Interferences	Sources of contamination
Personnel Requirements	Educational level and training of intended SOP users, number of operators required
Facilities Requirements	Mobile analytical laboratory, air conditioning, types of electricity, fume hood
Safety Precautions	Types of respirators, carbon monoxide monitors, special handling procedures; hazard warnings, placed immediately BEFORE relevant part of text
Apparatus	Larger items such as a meteorological tower, audit device, pH meter, gas chromatograph
Reagents/Materials	All chemicals used, including distilled or deionized water; grades of reagents; materials include smaller items such as filter paper, boiling chips, tubing, electrical wiring
Samples/Sampling Procedures	Sample preparation, collection, storage, transport, and data sheets
Calibration/Standardization	Preparation of standards and standard curves, frequency and schedule of calibrations
Analysis Procedures	Standard and custom-tailored methods for all analytes in all matrices
Calculations	Data reduction, validation, and statistical treatment, including confidence levels and outliers

Figure 304.2 Suggested Format for Standard Operating Procedures

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Data Reporting	Selection criteria, format, equations, units
Corrective Action	Criteria for initiation; individuals responsible
Method Precision and Accuracy	Tabular or narrative summary
B. Quality Control Sections	
Section	Typical Examples
QC Checks	Precision, accuracy, repeatability, reproducibility, blanks, spikes, replicates, selection criteria, and frequency summarized in tables
QC Controls	Audits, notebook checks, blind samples; control charts and graphs; actions to be taken when QC data approaches or exceeds QC limits
C. References	
Standard reference methods, reports, SOPs, journal articles; avoid citing unpublished documents	

Figure 304.2 Suggested Format for Standard Operating Procedures (continued)

General Information	Specific Example
SOP Number	SOP - 25
Section Number	Section 3
Revision Number	Revision No. 1
Date of Issue	April 3, 1997
Page ____ Of ____	Page 4 of 22

Figure 304.3 Document Control Format

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Preventive maintenance can be defined as a program of positive actions for preventing failure of monitoring parts and systems during their use⁷. These actions can include equipment cleaning, lubrication, testing, adjusting, reconditioning, etc. As preventive maintenance, these activities should be conducted on a routine schedule before failure and loss of data. If failures of a CEM occur on a regular basis the preventive maintenance section of the QA plan should be rewritten.

Each activity, by itself, may seem insignificant, but, when taken as a whole, the net result is a program with more reliable data, less downtime, and less cost in dollars, time, and grief. A good preventive maintenance program should include:

- Short description of each procedure
- Schedule and frequency for performing each procedure
- Supply of critical parts (on hand - not merely on a list)
- List of maintenance contracts for instruments used in critical measurements
- Documentation (log book) showing that maintenance has been performed as required by the maintenance contract, QA plan, or test plan

One of the points for an inspector to check is whether the facility has a written preventive maintenance schedule and whether it is being followed. A well maintained facility will indicate to the inspector that they care about the source and are working to keep emissions within permit and regulation limits (although this will be confirmed or not in the details of the inspection).

304.4.3 Corrective Maintenance

Few projects run perfectly, it is inevitable that failures will occur. A description of the corrective action to be taken in cases of equipment failures should be a part of the QA plan for a facility.

Many corrective action plans are embedded in the QC checks used for routine measurements and maintenance. Any statement ("If this happens, that will be done") must be accompanied by a designation of who will perform the corrective action. The corrective actions must then be documented in the appropriate notebooks and logbooks so that a record exists of the problems encountered and the solutions employed. If a pattern of failures is evident, more extensive corrective action may be needed or a change made to the preventive maintenance procedures.

Positive Actions for Preventing Failure

Responsibility Documentation

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304.4.4 Audits

An audit is a management tool used to answer the question: is the CEM system operating according to specification? It is a formal, detailed study of one or more aspects of the system by independent personnel and equipment. An audit is not conducted at random, but at specific times and against specific, predetermined, criteria.

Successful operation of a monitoring system depends on how well the people follow procedure, operate equipment, collect and evaluate data, and document their activities. An audit thus focuses on the people, procedures, equipment, data, and documentation of a monitoring system. After the audit, a report describes any problems found and may suggest appropriate corrective actions. Equally important, it also covers those aspects that are operating as specified. Thus, it covers the complete system, not just what needs attention.

The QA plan should serve as the basis of conducting audits on the CEM system. These audits include:

- Systems Audits - Examination of the entire monitoring system including the equipment, data, recordkeeping, data validation, operation, maintenance, calibrations, reporting, and QC procedures.
- Performance Audits - Audits in which the monitoring system is challenged with reference materials.
- Agency Audits - Audits in which an air pollution control agency conducts a systems or performance audit.

Systems Audits

Systems audits are comprehensive qualitative examinations of the entire monitoring program. A systems audit can be divided into Technical Systems Audits and Management Systems Audits.

Technical Systems Audit

The technical systems audit is the more common systems audit. It looks at the entire measurement system - all facilities, equipment, systems, record keeping, data validation, operations, maintenance, calibration procedures, reporting requirements, and QC procedures for a specific CEM project. The findings from

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the systems audit can be used to focus efforts on specific parts of the program that need attention to attain the desired data quality level.

A management systems audit examines the structures and processes used by management to achieve data quality. A management systems audit frequently covers multiple monitoring systems within a facility or companywide. Laboratory and field personnel are rarely involved in these audits.

Management Systems Audit

Performance Audits

A performance evaluation audit involves the analysis of a reference material of known value or composition or a concurrent reference method test. The performance audit may be conducted unscheduled (typically by an air pollution control agency representative) or on a schedule. A systems audit is sometimes conducted alongside a performance audit to give a complete picture of the monitoring system operation.

Appendix F of NSPS⁸ (Part 60 sources) requires a data accuracy assessment audit at least once each quarter. Three of four quarters this audit can be a cylinder gas performance audit (CGA). A relative accuracy test audit (RATA) comparing the results of the monitor with a reference method test is required the fourth quarter. Sources subject to the acid rain monitoring provisions⁷ (Part 75 sources) must conduct a linearity check performance audit (similar to an NSPS cylinder gas audit) quarterly and a relative accuracy test audit semiannually.

Data Accuracy Assessment CGA, RATA

Test frequency incentives in 40 CFR 75 (Appendix B, section 2.3.1) allow annual rather than semiannual RATA tests if a higher degree of accuracy is maintained as per one of the following conditions:

- The relative accuracy during the previous audit for an SO₂ or CO₂ pollutant concentration monitor (including an O₂ pollutant monitor used to measure CO₂ using the procedures in 40 CFR 75 Appendix B), or for a NO_x or SO₂ - diluent CEM system is 7.5% or less.
- Prior to 1 January 2000, the relative accuracy during the previous audit for a flow monitor is 10.0% or less at each operating level tested.
- On or after 1 January 2000, the relative accuracy during the previous audit for a flow monitor is 7.5% or less at each operating level tested.

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- On low flow (≤ 3.28 m/s, 10 fps) stacks and ducts, when the monitor mean is within ± 0.5 m/s (± 1.5 fps) of the reference method or achieves a relative accuracy of 7.5% (10.0% prior to 1 January 2000) or less during the previous audit.
- On low SO₂ emitting units (SO₂ concentrations ≤ 250 ppm or the equivalent mass emission rate), when the monitor mean is within ± 8 ppm (or equivalent mass emission rate) of the reference method or achieves a relative accuracy of 7.5% or less during the previous audit.
- On low NO_x emitting units (NO_x emission rate ≤ 86 ng/J, ≤ 0.20 lb/10⁶BTU) when the NO_x CEM system achieves a relative accuracy of 7.5% or less or when the monitoring system mean is within ± 4.3 ng/J (± 0.01 lb/10⁶BTU) or the reference method mean.

A maximum of two test trials may be performed to achieve results to qualify for the less frequent audits. Whenever two trials are performed, the results of the second trial must be used in calculating both the relative accuracy and bias.

Agency Audits

During their inspections at a facility, air pollution control agency personnel may conduct unannounced systems or performance audits. In addition, if the agency has doubts about a monitoring system, they may require the facility conduct a complete systems audit or performance audit.

304.5 RECORDKEEPING

Comprehensive records of all aspects of the monitoring system are extremely important. In litigation, the CEM records, test results, and audit results could be subject to the requirements of legal rules of evidence. It is, therefore, important that logbooks and data records be complete and up to date.

The results of quarterly audits are to be reported to the control agency in the Data Assessment Report (DAR). As a minimum, the DAR must contain:

- Source owner name and address;
- Identification and location of monitors;
- Manufacturer and model number of each monitor;
- Audit accuracy results;

DAR

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- Summary of corrective actions taken when the system was out of control;
- Accuracy results for audits determining whether the system has been brought back into control;
- Results from reference method performance audit samples.

A sample DAR can be found in 40 CFR 60 Appendix F and in Appendix A of this manual.

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305 REFERENCES

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3. Air Pollution Training Institute Course 474, Continuous Emission Monitoring Systems, Student Manual, September 1992.
4. Hinds, William C., Aerosol Technology, John Wiley and Sons Inc, New York, 1982.
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6. U.S.EPA, 1996, In Code of Federal Regulations, 40 CFR 60.13, Superintendent of Documents, Washington, D.C.
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9. U.S.EPA, 1994, Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I: A Field Guide to Environmental Quality Assurance, EPA/600/R-94/038a.
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Procedures for certifying continuous emission monitoring systems have been established by the U.S. EPA, the International Standards Organization (ISO), some states, and a number of European countries. Certification procedures are established as regulatory requirements and must be followed if the CEM system is to provide data acceptable to the regulatory agency requiring the CEM. Several different approaches to certification can be taken, however, most approaches require the comparison to an independent reference method. The U.S. performance specifications for NSPS sources are contained in 40 CFR 60 Appendix B.¹ Additional performance specifications for sources subject to acid rain provisions are contained in 40 CFR 75 Appendix A² and in 40 CFR 266³ for monitoring of hazardous waste incineration. Some states and local air pollution control districts have promulgated their own testing methods and requirements. Many others have incorporated, by reference, the EPA or state testing procedures.

Performance Specifications

It has been found that a monitor may work well in a laboratory or at one facility, but that same model may give erratic data at some other facility. These differences are generally a function of the integration of the CEM technology and the facility characteristics and configuration. Therefore, the monitor is not the controlling agent, but rather it is the total system that must be evaluated to demonstrate that accurate data can be provided. Certification must, therefore, be done on a case-by-case basis, rather than by blanket approval as given to ambient monitors.

Case-By-Case Certification

The test procedures, whether developed by the EPA, the state, or local districts, have been established to certify the CEM system as installed. The installation specifications, performance specifications, and test procedures have been developed with this intent. However, it should be noted that any modifications of the system, even following the performance specifications, will often require recertification to demonstrate that the reconfigured monitor still is producing accurate data in its specific installation. Long term operation of the CEM system depends on a thorough quality assurance program and diligent operation.

The performance specifications follow a basic format (Table 400.1). They include installation and measurement locations, the actual equipment and performance specifications, and test procedures. For the gaseous monitors the procedures are detailed in PS 2, but they are not all reprinted in the other sections, relying instead on referencing to PS 2. The two major criteria that CEM systems must meet are: 1) calibration drift and 2) relative accuracy. In addition to the performance specification tests in Appendix B, sources using CEMs to determine compliance must also follow the quality assurance and quality control procedures

Calibration Drift and Relative Accuracy

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Table 400.1 Format and Content of Performance Specifications

	PS1 Opacity	PS2 SO ₂ , NO _x	PS3 O ₂ , CO ₂	PS4 CO	PS5 TRS	PS6 Velocity	PS7 H ₂ S	PS8 VOC	PS9 Gas Chromatograph
1	Applicability and Principle	Applicability and Principle	Applicability and Principle	Applicability and Principle	Applicability and Principle	Applicability and Principle	Applicability and Principle	Applicability and Principle	Applicability and Principle
2	Definitions	Definitions	*	*	*	Definitions and PS2*	*	*	Definitions
3	Apparatus	Installation and Measurement Location Specifications	*	*	*	*	*	*	Installation and Measurement Location Specifications
4	Installation Specifications	Performance and Equipment Specifications	Performance and Equipment Specifications and 4.1*	Performance and Equipment Specifications and 4.1*	Performance and Equipment Specifications and PS2*	Performance and Equipment Specifications and 4.1*	Performance and Equipment Specifications and 4.1*	Performance and Equipment Specifications and 4.1*	Performance and Equipment Specifications
5	Design and Performance Specifications	Performance Specification Test Procedure	*	*	*	*	*	*	Performance Specification Test Periods
6	Design Specifications Verification Procedure	Calibration Drift Test Procedure	*	*	*	Calibration Drift Test Procedure	*	*	Equations
7	Performance Specification Verification Procedure	Relative Accuracy Test Procedure	Relative Accuracy Test Procedures and 7.1, 7.2, 7.3, 7.5*	Relative Accuracy Test Procedures and 7.1, 7.2, 7.3, 7.5*	Relative Accuracy Test Procedures and 7.1, 7.2, 7.3, 7.5*	Relative Accuracy Test Procedures and 7.1, 7.2, 7.3, 7.5*	Relative Accuracy Test Procedures and 7.1, 7.2, 7.3, 7.5*	Relative Accuracy Test Procedures and 7.1, 7.2, 7.3, 7.5*	Daily Calibrations
8	Equations	Equations	*	*	*	*	*	*	Reporting
9	Reporting	Reporting	*	*	*	*	*	*	
10	Retest	Alternative Procedures	*	NA (Alternative Procedures in PS4A)	NA	NA	NA	NA	
11	Bibliography	Bibliography	*	Bibliography	Bibliography	Bibliography	Bibliography	*	

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of Appendix F of 40 CFR 60. In addition to the nine Performance Specifications listed in Table 400.1, Performance Specification 10 for metals CEMs, PS 11 for particulate matter monitoring, PS 12 for mercury emissions monitoring, PS 13 for HCl, PS 14 for Cl, and PS 15 for fourier transform infrared spectrographic (FTIR) CEMs are being developed. These last six performance specifications are still under development.

Calibration Drift "The difference in the CEM system's output readings from the established reference value after a period of operation during which no unscheduled maintenance, repair, or adjustment took place."⁴

Relative Accuracy "The absolute mean difference between the gas concentration or emission rate determined by the CEM system and the value determined by the reference methods (RM) plus the 2.5 percent error confidence coefficient of a series of tests divided by the mean of the RM tests or the applicable emission limit."⁴

The calibration drift specification is generally not difficult for most CEM systems to satisfy. The actual calibration drift and relative accuracy specifications are given in Table 400.2 for NSPS¹ sources and Table 400.3 for Acid Rain (Part 75)² sources. Table 400.3 lists the relative accuracy limits for Part 75 sources passing their RATA tests. An incentive program (see Section 404.2.3, page 69) exists in the regulations whereby sources meeting more stringent error limits may reduce their testing frequency from semiannual to annual.

The accuracy of a measured value is an expression of its relationship to a standard or "true" value. For source emission measurements, the reference method is defined as being the true value. This depends on the proper application of the reference methods and stresses the importance of the test observer's knowledge, performance test quality assurance, and the use of EPA audit samples during the test and analysis.

The U.S. EPA procedure for calculating CEM accuracy uses a method for the comparison of data pairs and results in the expression of "relative accuracy." The relative accuracy is composed of two terms: one expressing the average deviation of the CEM value from the reference value and the other giving an estimate of the spread, or precision, of the results.

The relative accuracy expression essentially gives an estimate of accuracy only at one point: the average value of the emissions (as defined by the reference

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Table 400.2 Performance Specifications for NSPS Sources

PS	Gases	Calibration Drift	Relative Accuracy
2	SO ₂ , NO _x	2.5% of span	20% of RM in units of the standard 10% of applicable standard [stds. > 130 ng/J, 0.30 lbs/10 ⁶ BTU] 15% of applicable standard [stds. > 86 ng/J and <130 ng/J (>0.20 lbs/10 ⁶ BTU and < 0.30 lbs/10 ⁶ BTU)] 20% of applicable standard [stds. < 86 ng/J (0.20 lbs/10 ⁶ BTU)]
3	O ₂ , CO ₂	0.5%	20% of RM value or 1.0% (whichever is greater)
4	CO	5% of span for 6 of 7 test days	10% of RM value in units of the standard or 5% of applicable emission standard (which- ever is greater)
5	TRS	5% of span for 6 of 7 test days	20% of RM value in units of the standard or 10% of applicable emission standard (which- ever is greater)
6	Flow	3% of span	20% of RM value in units of the standard or 10% of applicable emission standard (which- ever is greater)
7	H ₂ S	5% of span for 6 of 7 test days	20% of RM value in units of the standard or 10% of applicable emission standard (which- ever is greater)
8	VOC	2.5% of span	20% of RM value in units of the standard or 10% of applicable emission standard (which- ever is greater)
9	GC	10% of certified value	10% of the certified value

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Table 400.3 Performance Specifications for Acid Rain (Part 75) Sources

Parameter	Calibration Drift	Relative Accuracy
SO ₂	2.5% of span or 5 ppm	10% or 15 ppm if < 250 ppm; ±12.9 ng/J (0.03 lb/10 ⁶ BTU) for SO ₂ -diluent monitors ≤215 ng/J (0.5 lb/10 ⁶ BTU)
NO _x	2.5% of span or 5 ppm	10% or ±8.6 ng/J (0.02 lb/10 ⁶ BTU) if ≤86 ng/J (0.20 lb/10 ⁶ BTU)
CO ₂ , O ₂	0.5% CO ₂ or O ₂	10% or mean difference between RM and CEM <1.0% CO ₂ or O ₂
Flow	3% of span	15% (10% beginning 1 Jan 2000) or ±0.66 m/s (2 fps) if flow ≤3.28 m/s (10.0 fps)

method) at the time the test was conducted. It has little statistical relevance, and does not guarantee the accuracy at other emission levels. At low emission levels, a modified relative accuracy expression employing the emission standard rather than the reference method results is used to accommodate problems associated with the expression. Such modifications are regulatory constructs and have little statistical meaning. They are only used to facilitate the calculations.

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The performance specifications for gases do not give design specifications for analyzers, as is done in PS 1 for opacity monitors. The gas monitors can be designed in any fashion desired, provided they are functional. The primary criterion is that the CEM should give data comparable to that obtained by an independent reference method. For transmissometers for opacity there are few inexpensive and independent reference methods for determining the accuracy. Therefore, transmissometers rely heavily on design criteria (and design criteria certification tests) while gaseous CEMs place more emphasis on the comparative tests.

Appendix B of 40 CFR 60¹ contains the performance specifications for CEMs for use in NSPS program monitoring. For the acid rain program, 40 CFR 75 Appendix A² contains the pertinent specifications and tests. Part 75 includes a linearity

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check, cycle / response time check, and a bias adjustment factor in addition to the calibration error and relative accuracy tests of the NSPS requirements. Most state or locally required monitoring programs follow the NSPS requirements to a greater or lesser extent.

401.1 CERTIFICATION TESTS FOR GASES

The performance specification test (PST) is required by the EPA and state agencies to certify CEM systems. The test evaluates how well the system performs in the real-world physical and environmental conditions at the plant. The ability to sample and measure the flue gas and the CEM's responses to voltage fluctuations, stack vibration, stack and ambient temperature extremes, etc. are checked by the calibration drift and relative accuracy tests. The PST is designed to give a realistic evaluation of the instrument's operation under those potentially harsh conditions.

System Performance

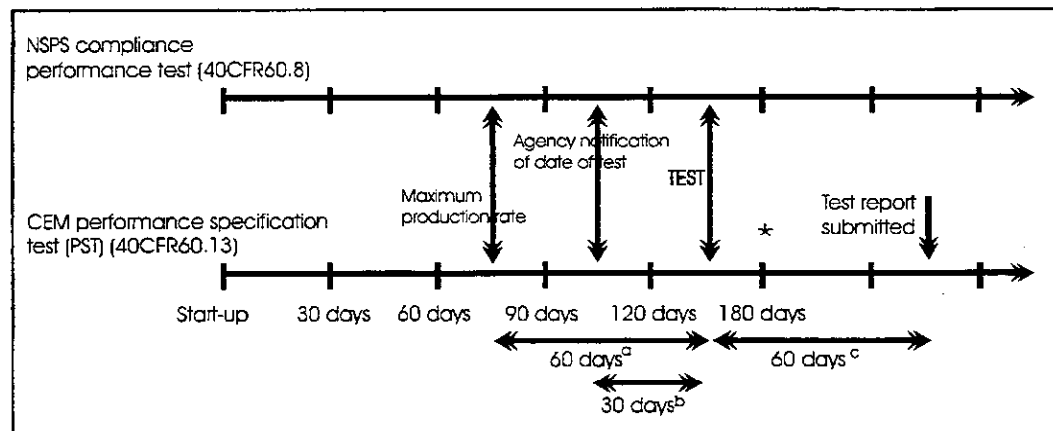


Figure 401.1 Time Frame for Conducting NSPS Performance Tests and PSTs; * last day after start-up to conduct test, **a:** maximum time window after maximum production has been achieved in which to conduct test, **b:** minimum time window for agency notification of testing, **c:** maximum time window to submit test report

401.1.1 Preparing for the PST

The PST must be conducted shortly after plant startup, or the startup of a modified facility,^{5,6} although a time allowance is given to get the process running

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smoothly. From the initial plant startup, a date is set by which time the facility must conduct both NSPS performance (compliance) tests and the PSTs. This time period is given in 40 CFR 60.8 (Figure 401.1). Which states that the performance tests must be conducted within 60 days of achieving the maximum production rate, but no more than 180 days after initial startup. Provisions of 40 CFR 60.13 also require that the monitoring systems be operational before conducting the compliance performance tests. They also require that the performance evaluation of the monitoring systems be conducted during the compliance performance tests or within 30 days.

The PST is generally conducted by a source testing contractor. Representatives from the CEM vendor and the agency (state, local, and/or EPA) may also wish to be present for the tests.

The California Air Resources Board maintains a certification process for source testing contractors (<http://arbis.arb.ca.gov/cd/sb.htm#contractor>). Many air pollution control districts in the state require that a testing contractor be on the CARB list as a means of assuring competent testing personnel. In addition, the EPA maintains Internet sites with test method information, laboratory accreditation information, a list of testing companies and laboratories, and other CEM and testing information (<http://ttnwww.rtpnc.epa.gov/html/emticemic/emtic.htm#EM02>).

Often the vendor must guarantee that the system will pass the PST. Therefore, the vendor representative would want to observe the test for any problems with the system or its implementation, in which case the system may need to be modified or replaced. The agency representative is primarily interested in the test methods and procedures. If problems occur, the agency representative may be called on to approve (or disapprove) test method modifications to suit the source being tested.

A pretest meeting should be held before the date of the test. During the pretest conference the process to be tested and procedures to be followed are defined and planned. This is the time to discover any oddities about the source that will require alternative test methods or modifications of the standard methods. During the pretest conference the agency should also give the source test contractor the format and requirements of the final report. One of the most important products of a pretest conference is the coordination between the plant personnel, source testing company personnel, and agency observers.

Time Table

Test Company Certification

Vendor Rep- resentatives

Pretest Con- ference

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Checklists to be used and data to be recorded during the test should also be considered. It is common to design data printouts to be produced during the test that will be most suited to coordinating the data between the CEMs and the reference methods tests.

The pretest conference should include personnel from the facility being tested, the plant environmental engineer/CEM coordinator, control agency representative, a source test contractor representative, and a CEM system vendor representative. Topics at the meeting should include:

- Plant operational status
- Plant emission control equipment status
- CEM system operational status
- Calibration gases: concentrations and certifications
- Test methods to be used, including alternatives and method modifications
- Test schedule
- Test report requirements

There also should be a plant tour, concentrating on the areas of the plant that will be important during the test: stack facilities, control room, CEM room, etc.

401.1.2 The PST Calibration Drift Test

The zero and high-level drift test examine a CEM system's ability to hold its calibration over a period of time. During the certification test the calibration drift test is conducted over a period of 168 hours while the plant is operating at more than 50% of its normal load. The CEM calibration drift is evaluated at 24 hour intervals by introducing zero (or low level, 0 to 20% of the high level value) and high-level (50 to 100% of the recorder high-level) span gases. An in-situ or non-extractive monitor can determine the calibration drift with gas cells or optical filters.

Operational
Test Period

Operation
Rate

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The usual protocol for the test is:

- Day 0 Introduce zero gas into the system. Adjust the zero reading.

 Introduce high-level gas into the system. Calibrate the system to this value.
- Day 1 Inject zero gas into the system after 24 hours. Record the value. (If desired, the system may be adjusted to the zero set on day 0.)

 Inject high-level gas into the system. Record the CEM system reading. (If desired, the system may be adjusted to the calibration value set on day 0.) If the system zero was not reset prior to injecting the high-level gas, subtract the zero reading and record the result.
- Day 2 - 7 Repeat the steps conducted on Day 1.

The data is entered into a form, such as that in Appendix A. Calibration drift is reported in percentages obtained by dividing the difference between the certified cylinder gas reference value (calibration value) and the value reported by the monitor (monitor value) by the instrument span value:

$$d_{cd} = \frac{\text{cylinder gas reference value} - \text{monitor value}}{\text{span value}} \times 100$$

If periodic automatic, or manual, adjustments take place to bring the system into calibration, the calibration drift must be determined immediately before these adjustments take place or the test conducted in such a way that the drift can be determined. In some CEM systems, the system microprocessor will automatically zero and calibrate the system daily. In such a system the amount of correction invoked by the system must be recorded and displayed.

The performance specification does not specify the quality of gas to be used for the calibration drift test. Only the differences between daily readings are important in the drift calculations. There would be more confidence in the system, however, if the degree of uncertainty associated with the calibration gases were minimized. Also, since Protocol 1 calibration gases or Certified Reference Materials (CRM) are required for the QA audits required by 40 CFR 60, Appen-

Adjustments

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Calibration Drift Test Data

Person Conducting Test	Joe	Analyzer Manufacturer	Sam's CEMs
Affiliation	Joe's Source Test Co.	Model/Serial Number	11456
Date	3/27/90	Location	Acme Power Plant, Coal Unit
Instrument Span Value	1500 ppm SO ₂		

Day	Date and Time	Calibration Value	Monitor Value	Difference	Percent of Span Value
Low Level					
0	3/27/90 9:00	0	Zeroed	--*	--*
1	3/28/90 9:10	0	3	-3	-0.20
2	3/29/90 9:15	0	5	-5	-0.33
3	3/30/90 9:00	0	6	-6	-0.40
4	3/31/90 9:15	0	2	-2	-0.13
5	4/01/90 9:10	0	-3	+3	0.20
6	4/02/90 9:15	0	-5	+5	0.33
7	4/03/90 9:20	0	-4	+4	0.27
High Level					
0	3/27/90 9:40	1370	Spanned	--*	--*
1	3/28/90 9:35	1370	1375	-5	-0.33
2	3/29/90 9:40	1370	1375	-5	-0.33
3	3/30/90 9:45	1370	1380	-10	-0.67
4	3/31/90 9:50	1370	1385	-15	-1.00
5	4/01/90 9:45	1370	1380	-10	-0.67
6	4/02/90 9:50	1370	1380	-10	-0.67
7	4/03/90 10:00	1370	1375	-5	-0.33

Figure 401.2 Example Calibration Drift Test Data Sheet

dix F, if Protocol 1 gases were used for the PST, the subsequent data quality would be better correlated with its initial performance.

Example Calibration Drift Calculation⁷

A new 150 MW unit was added to the Acme Power Plant in Calvander, North Carolina. The unit was an affected facility under Subpart Da for electric utility steam generating units. The unit began startup on 12 November, 1989, and the state agency, through its delegated NSPS authority, had required the installation of an SO₂ CEM system. The plant had installed a flue gas desulfurization system to meet SO₂ emission requirements. The maximum estimated hourly potential SO₂ emissions from the coal fired unit were estimated to be equivalent to 3000

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ppm. According to the requirement of Subpart Da, the inlet SO₂ monitor span value is 3750 ppm and the outlet monitor span value is 1500 ppm.

On day 0, 27 March, 1990, the outlet SO₂ monitor was zeroed using a cylinder of compressed nitrogen gas and spanned with a calibration gas having a value of 1368 ppm. On days 0 through 7 the data in Figure 401.2 were obtained. For both the zero and high-level tests there are no instances in which the drift exceeded 2.5% of the span, therefore, the unit has passed the calibration drift test.

401.1.3 The Relative Accuracy Test

The relative accuracy test is the most important part of the performance test and the most expensive to perform. As discussed in the previous section, coordination and communication are key in successfully completing the test.

The relative accuracy test is conducted to determine if a CEM system will give data comparable to the data obtained from a reference method compliance test. The relative accuracy test results are reported in units of the standard; therefore, the test may include data from more than just the pollutant monitor. The accuracy determination may include the pollutant, diluent, and flow monitors to perform the calculations in term of the standard. For example: the SO₂ emission standards, in ng/J, for FFFSG require an F-factor calculation using SO₂ and O₂ (or CO₂) data. To report on a mass emission rate basis (e.g. kg/hr), the stack flow rate must be known and the flow monitor data included in the calculations.

Compare CEM to Reference Method Test

Reference Method Location and Traverse Points

The relative accuracy test is relative only to the comparison of the CEM and the reference method. It does not certify that the CEM reflects the true emissions from the facility. The typical point extractive CEM samples the emissions at a single point in the stack. The reference method test samples at least three points for the performance test (more when the compliance test is also conducted); the more points sampled, the truer the sample will represent the actual emissions.

The reference method tests do not necessarily have to be taken at the same location as the CEM monitoring location. For example: the CEM may monitor on a duct leading into the stack for ease of operation and maintenance and the reference method tests could be conducted at a point located in the stack.

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The reference method sampling points are chosen to provide representative samples over the duct or stack cross section. As a minimum, samples are taken on a three point traverse on a measurement line that passes through the centroid and are in the direction of any expected stratification (i.e. in the plane of the bend, etc.). For a stack or duct less than 2.4 meters in diameter, samples are taken at points that are 16.7, 50, and 83.3% of the diameter (Figure 401.3a). For a stack or duct larger than 2.4 meters, and where stratification is not expected, the sampling points may be located at 0.4, 1.2, and 2.0 meters from the stack or duct wall (Figure 401.3b). The sampling points must be within 3 cm of the specified point. The second option is not allowed after wet scrubbers or where two gas streams with different composition are combined.

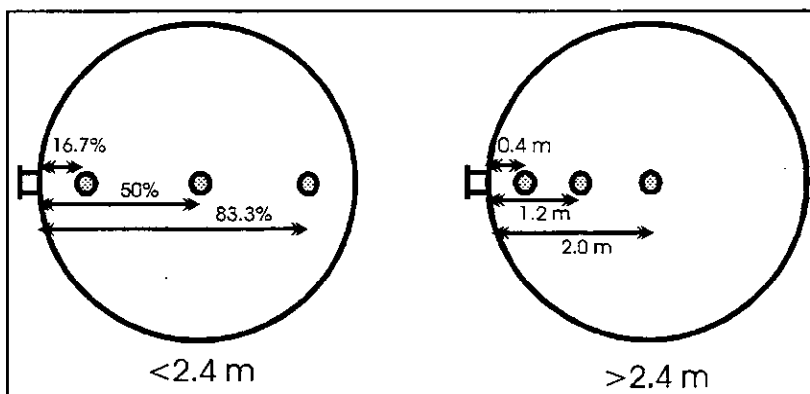


Figure 401.3 Reference Method Traverse Points a) Diameter <2.4 Meters, b) Diameter >2.4 Meters

The sampling locations along the stack are the same as the location requirements of the CEM and the minimum source testing requirements, i.e. at least two stack diameters downstream of any disturbance and at least one-half diameter upstream of any disturbance. The reference method sampling point should not interfere with the CEM probe. If the reference method measurement line interferes with the CEM, it should be displaced by a distance of 30 cm or 5% of the equivalent diameter (whichever is less), from the centroidal area.

Relative Accuracy Test Procedures

The primary sampling strategy for the relative accuracy test is to take concurrent data sets from the CEM system and the reference method. In doing this care must be taken to account for the time lags in each measurement system. The most straightforward case is when an instrumental reference method is compared with an extractive CEM system. In this case the time for the sample to travel the

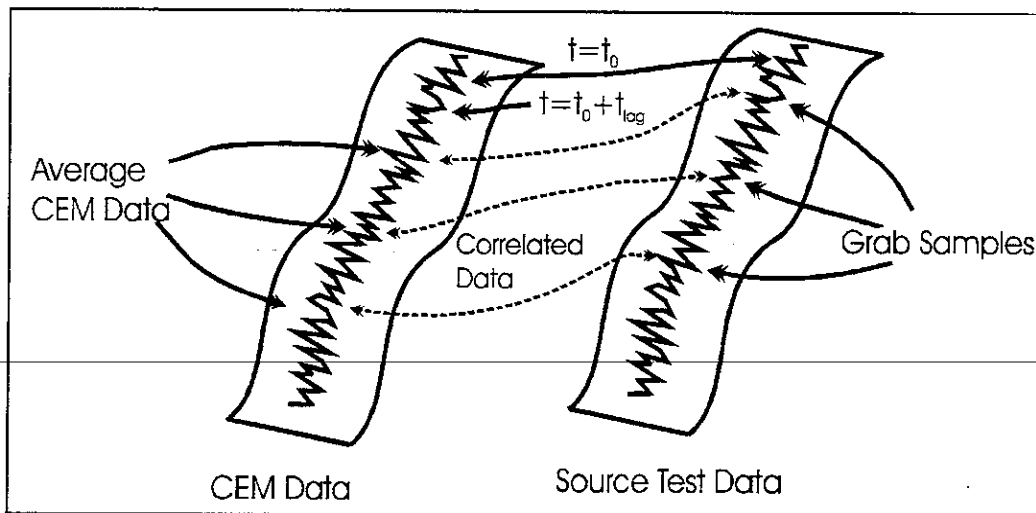


Figure 401.4 Effect of Short Term Data and Response Time Lag

umbilical, conditioner, and for the instrument to respond in each system must be accounted for (Figure 401.4). Paragraph 7.2.2 of PS 2 recommends that the arithmetic average of the CEM system at the time of each grab sample be used instead of the average over the entire test run.

A problem also arises when grab samples are taken in the reference method, or when a time-shared CEM system samples emissions for only a few minutes to perform one cycle of operation for each 15 minute period (40 CFR 60.13(e)(2) requirement). This can result in directly comparable data for only a few minutes during each 21 minute sample period.

Reference method data is obtained at each of at least three sampling points on the traverse line when conducting the test. The following options are available:

- Integrated manual reference method - Sample seven minutes at each point.
- Instrumental (alternate) reference method - Sample seven minutes at each point.
- Grab sample manual reference method - Sample the three points simultaneously (within three minutes) or sample at equal intervals over a period of 21 minutes or less.

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These procedures are repeated to give a total of nine data sets. Each data set is obtained within a period of 30 to 60 minutes. The tester may choose to perform more than nine sets of RM tests. The tester may then, at his discretion, reject a maximum of three sets of data, so long as at least nine data sets are used to determine the relative accuracy. All data sets, including the rejected sets, must be reported.

Diluent and moisture measurements are important in the emission calculations. The diluent and moisture samples should be obtained simultaneously with the pollutant data (although in PS 2 they may be obtained at any time during the 30 to 60 minute sampling period).

Relative Accuracy Test Calculations

The relative accuracy of the CEM system is determined by a comparison of the reference method results with the concurrent CEM data (each in units of the standard). Manual reference methods are usually reported from the laboratory in milligrams of pollutant per dry standard cubic meter (mg/dscm) or milligrams per dry standard cubic foot (mg/dscf) corrected to standard temperature of 293 K (528 R) and pressure of 760 mmHg (29.92 in. Hg). Where the results need to be converted from parts per million (dry) to milligrams per dry standard cubic meter, multiply by:

$$C_s \text{ (mg / dscm)} = C_s \text{ (ppm)} \times \frac{\text{MW(g / g - mole)}}{22.414(\text{l / g - mole}) \times \frac{T}{273.15}}$$

where MW is the molecular weight of the pollutant gas (e.g. 64.06 g/g-mole for SO₂) and T is the temperature at which the ppm reading is reported, typically EPA standard temperature of 20°C (293.15K). This calculation assumes the data is on a dry basis; to convert a wet measurement to dry, multiply the pollutant concentration by the dry fraction (i.e. multiply the wet concentration by $[1 - B_{ws}]$, where B_{ws} is the moisture fraction of the flue gas).

The concentration is then calculated in units of the standard by incorporating the diluent monitor data and an F_d factor (if required). For a kraft pulp mill, municipal waste combustor, etc. the units of the standard are in ppm corrected to eight or ten percent oxygen (kraft pulp mills) or seven percent oxygen (municipal waste combustors). Therefore the ppm emission should be calculated:

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$$C_s (\text{ppm}_{d,c}) = C_s (\text{ppm}_d) \frac{20.9 - O_{2\text{reg}}}{20.9 - O_{2d}}$$

where $O_{2\text{reg}}$ is the oxygen reporting value in the regulation and O_{2d} is the dry oxygen content of the flue gases. A similar equation is used for calculating the emissions in terms of mass per gross calorific value (ng/J or lb/million BTU):

$$E = C_s \times F_d \times \frac{20.9}{20.9 - O_{2d}}$$

NSPS subparts D, Da, and Db (among others) require mass per gross calorific value reporting.

The F_d term is an oxygen based dry F factor used for determining the flue gas emissions in terms of the emission rate, expressed in nanograms per joule (or pound per million BTU). It is a ratio of the theoretical volume of dry gases (V_t) given off by complete combustion of a known amount of fuel to the high heating value (GCV) of the fuel burned.

$$F_d = \frac{\text{volume of dry combustion gas per kilogram}}{\text{gross calorific value per kilogram}} = \frac{V_t}{\text{GCV}}$$

The values of the components of the F factor are determined by fuel analysis. Some facilities use tabulated values of the F_d factor and others (especially large facilities) calculate an F_d factor for the specific fuel being burned. There are two types of fuel analysis, proximate and ultimate analysis:

Proximate analysis - a fuel analysis procedure that expresses the principal characteristics of the fuel as: 1) percentage of moisture, 2) percentage of ash, 3) percentage of volatile matter, 4) percentage of fixed carbon, 5) percentage of sulfur, 6) heating value, and 7) ash fusion temperature.

Ultimate analysis - the determination of the exact chemical composition of the fuel without paying attention to the physical form in which the components appear. The analysis is generally given in terms of percentage hydrogen, percentage carbon, percentage sulfur, percentage nitrogen, and percentage oxygen.

The data generated in an ultimate analysis of a fuel allow the calculation of the F_d factor. Each of the individual chemical components contribute to the total

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volume (V_t) based on the percentage present in the fuel. An F factor can be calculated for any fuel for which the composition of all constituents is known:

$$F_d = 10^{-5} \frac{[22.7(\%H) + 9.57(\%C) + 3.54(\%S) + 0.86(\%N) - 2.85(\%O)]}{GCV}$$

(for metric units; dscm/J) or:

$$F_d = 16^6 \frac{[3.64(\%H) + 1.53(\%C) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{GCV}$$

(for English units; dscf/million BTU)

These equations account for the stoichiometric amount of oxygen - that amount of oxygen necessary to oxidize the fuel completely to its combustion products. An industrial facility burning fuel adds a stoichiometric amount of air (oxygen and nitrogen) and some excess air to assure complete combustion of the fuel. The stoichiometric amount of oxygen percent would be consumed in combustion of the fuel. The remaining oxygen is in excess and dilutes the combustion gases. As a result the Q_s would be higher and must be corrected in order to calculate V_t . The volume of the combustion products is related to the excess air as follows:

$$V_t = Q_s \times (\text{Dilution air correction term}) = Q_s \times \frac{20.9 - \%O_{2d}}{20.9}$$

Because the heat released is not affected by the dilution air we have:

$$F_d = \frac{V_t}{Q_H} \quad \text{or} \quad \frac{Q_s}{Q_H} = F_d \left[\frac{20.9}{20.9 - \%O_{2d}} \right]$$

With C_d equal to the concentration of the pollutant on a dry basis:

$$E = C_d F_d \frac{20.9}{20.9 - \%O_{2d}}$$

The dry F factor is used for emission rate calculations when both the pollutant and oxygen are measured on a dry basis. On a wet basis the denominator of the function becomes $[20.9(1-B_{ws}) - \%O_{2w}]$.

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After the emissions measurements are calculated in their proper units, the differences between the reference method and CEM data sets are calculated:

$$d_i = RM_i - CEM_i$$

Next, the mean difference is calculated. When calculating the mean of the differences it is important to keep the sign when performing the summation; especially for Part 75 sources, where a bias correction factor is required.

The standard deviation and confidence coefficient are calculated to account for the margin of error in the reference method and CEM determinations.

$$S_d = \left[\frac{\sum d_i^2 - \frac{(\sum d_i)^2}{n}}{n - 1} \right]^{1/2}$$

$$CC = t_{0.975} \frac{S_d}{\sqrt{n}}$$

where $t_{0.975}$ is the statistical t value derived from the one-tailed t test corresponding to a probability that a measured value will be biased at the 95% level of confidence (Table 401.1).

Table 401.1 t Values

n	$t_{0.975}$	n	$t_{0.975}$	n	$t_{0.975}$
2	12.706	7	2.447	12	2.201
3	4.303	8	2.365	13	2.179
4	3.182	9	2.306	14	2.160
5	2.776	10	2.262	15	2.145
6	2.571	11	2.228	16	2.131

These values are already corrected for n-1 degrees of freedom. Use n equal to the number of individual values

The relative accuracy is then calculated by dividing the mean of the differences plus the confidence coefficient by either the mean reference method tests or the applicable standard:

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Relative Accuracy Determination											
Person Conducting Test				Joe		Analyzer Manufacturer				Sam's CEMs	
Affiliation				Joe's Source Test Co.		Model/Serial Number				11456	
Date				4/17/90		Location				Acme Power Plant, Coal Unit	
Pollutant SO ₂											
Run No.	Date	Time Start	Time End	Reference Method			CEM			Difference	
				O ₂ %	C _s mg/dscm <small>Units</small>	E ng/J <small>Units</small>	O ₂ %	C _s ppm <small>Units</small>	E ng/J <small>Units</small>	d _i ng/J <small>Units</small>	d _r ² ng/J <small>Units</small>
1	4/17/90	8:55	9:16	8.2	1006.3	437.2	7.9	382	431.8	5.4	29.16
2	4/17/90	10:25	10:46	8.6	946.3	424.5	7.9	389	439.7	-15.2	231.04
3	4/17/90	11:55	12:28	8.1	974.6	420.1	7.6	384	424.2	-4.1	16.31
4	4/17/90	15:02	15:26	8.6	1009.9	453	7.6	379	418.7	34.3	1176.49
5	4/17/90	16:25	16:48	8.0	1006.3	430.4	7.7	363	404.1	26.3	691.69
6	4/18/90	8:40	9:05	8.5	1024	455.6	7.6	354	391.1	64.5	1190.25
7	4/18/90	9:50	10:11	7.8	935.7	394.1	7.2	323	346.4	47.7	2275.29
8*	4/18/90	10:55	11:16	7.0	932.2	370	5.9	327	320.3	49.7	2470.09
9*	4/18/90	13:45	14:06	9.7	1027.5	506.2	8.8	328	398.3	107.9	11642.41
10	4/18/90	15:15	15:27	8.4	995.7	439.5	7.8	353	395.9	43.6	1900.96
11*	4/18/90	16:25	16:46	12.1	964	604.4	7.9	322	363.9	240.5	57840.25
12	4/18/90	17:35	17:58	8.3	826.3	361.8	7.8	350	392.6	-30.8	948.64
Sum										171.7	8460.33
Average						424.02		404.94	19.08		

* = data points not used in calculation

$$S_d = \left(\frac{\sum d_i^2 - \frac{1}{n}(\sum d_i)^2}{n-1} \right)^{\frac{1}{2}}$$

$$CC = t_{0.975} \frac{S_d}{\sqrt{n}}$$

$$RA = \frac{|\bar{d}| + |CC|}{RM} \times 100$$

n	9
d _i	171.7
d _r ²	8460.3
\bar{d}	19.08
S _d	25.46
t _{0.975}	2.365
CC	20.07
RM	424.02
Std.	500
RA	9.23

Figure 401.5 Example Relative Accuracy Test Data Sheet

$$RA = \frac{|\bar{d}| + |CC|}{RM}$$

An example data sheet is in Appendix A of this manual.

Example Relative Accuracy Calculation⁷

A CEM system has just been installed at a bituminous coal-fired power plant. The system includes extractive SO₂ and oxygen monitors. Moisture is removed from the sampled flue gas by condensation before the sample reaches the analyzers. During the performance test the reference method data was obtained by manual methods; Reference Method 6 for SO₂ (barium-thorin titration) and Reference Method 3 (ORSAT) for oxygen. The CEM system averaged the monitor output data during the period the reference method data were being obtained. The data are presented on a relative accuracy test form in Figure 401.5. A blank relative accuracy test data form is included in Appendix A, this form is designed to use a separate form for each pollutant/monitor certified.

A total of 12 samples were taken. Since a maximum of three samples may be deleted, samples 8, 9, and 11 were deleted from the calculations, leaving nine samples in the calculations. The deleted samples are reported on the data form and noted as not used in the calculations.

The Reference Method 6 data were reported from the laboratory in mg/dscm. These data were then converted to units of the standard (E, ng/J) using an F_d factor, 2.64×10^{-7} dscm/J, derived from analysis of the fuel and the results of the Method 3 ORSAT samples taken during the test.

The CEM pollutant data were recorded by the system in parts per million. These data were converted to a mass emission rate and then calculated in terms of the standard like the reference method data. The oxygen content of the flue gas reported by the diluent monitoring system must be used for the CEM emission rate calculations.

The difference (d_i) between the reference method and CEM data for each run was calculated. Then the standard deviation (S_d), confidence coefficient (CC), and relative accuracy were calculated.

The results of the relative accuracy test results show that the monitor meets the NSPS limit of 20% (relative accuracy results = 9.23%). If the value of the standard were used to calculate the RA rather than the reference method, the RA results would be 7.83%.

Nine of the 12 runs were used in the relative accuracy calculations. If all 12 runs had been used, the relative accuracy would have fallen to 20.80% using the mean

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of the reference method data (outside of the allowable range) and 18.35% using the value of the standard (barely within the passing range).

The preceding relative accuracy example scenario was for an initial CEM certification. During the Relative Accuracy Test Audit (RATA), required once every four calendar quarters by 40 CFR 60 Appendix F, the procedures and calculations would be the same. The biannual (or annual, if qualifying) RATA tests for the Acid Rain Program (40 CFR 75 Appendix B) would also follow this procedure, with the addition of a bias adjustment factor (BAF). The BAF is discussed in Section 404.1.2 of this manual.

Alternative Procedures

An alternative relative accuracy procedure in Performance Specification 2 for SO_2 and NO_x may be used if the emissions are less than 50% of the standard and the data from the CEM are not used to determine continuous compliance with the applicable standard. The alternative procedure is a check of the CEM system using NIST or NIST traceable audit gases or certified calibration cells and is easier to perform than the relative accuracy test.

Low Emission Sources

The alternative procedure consists of 1) conducting a complete CEM systems status check and 2) challenging each monitor with cylinder gases of known concentrations or certified calibration cells. The systems status check should include the operation of the light source, signal receiver, timing mechanism functions, data acquisition and reduction functions, data recorders, mechanically operated functions (mirror movements, zero pipe operation, calibration gas valve operations, etc.), sample filters, sample line heaters, moisture traps, and other related functions of the CEMS, as applicable. All parts of the system must be functioning properly before proceeding with the alternate RA procedure.

The calibration gas check is performed by challenging each monitor (and associated diluent monitor, if applicable) with cylinder gases or certified calibration gas cells that produce known responses at two levels (Table 401.2).

The average of three responses is used in determining the relative accuracy. These calculations of the relative accuracy procedure do not include a confidence coefficient. The relative accuracy is calculated as follows:

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Table 401.2 Alternative Relative Accuracy Calibration Ranges

Measurement Point	Pollutant Monitor	Diluent Monitor	
		CO ₂	O ₂
1	20 - 30 percent of Span	5 - 8 percent	4 - 6 percent
2	50 - 60 percent of Span	10 - 14 percent	8 - 12 percent

For pollutant gases:

$$RA_{alt} = \left| \frac{\bar{d}}{AC} \times 100 \right|$$

where:

d = difference between the response and the known concentration

AC = the known concentration of the cylinder gas or calibration cell

For diluent CEMs

$$RA_{alt} = |\bar{d}|$$

The limit for the relative accuracy of the pollutant monitors is less than or equal to 15 percent and for the diluent monitors is less than or equal to 0.7 percent O₂ or CO₂.

Waiver of the relative accuracy test in favor of the alternative procedure does not preclude the requirements to complete the calibration drift tests or any other requirements specified in the applicable regulations for reporting CEMs data and performing CEMs drift checks or audits.

401.1.4 Performance Specification Tests for Oxygen and Carbon Dioxide

Performance Specification 3 gives the specifications for oxygen and carbon dioxide monitors. As was discussed in Section 400 and summarized in Table 400.1, many of the specifications and procedures refer back to Performance Specification 2.

PS 3

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Performance Specification 3 applies to O₂ and CO₂ monitors that are not used as diluent monitors associated with other CEMs. Data from diluent O₂ and CO₂ monitors are evaluated as part of the relative accuracy of the pollutant monitors. Although PS 3 may not be required for many O₂ and CO₂ monitor installations, the facility and agencies often require that PS 3 be conducted to document the operation of the diluent subsystem. This information is helpful in evaluating vendor guarantees and interpreting future QA checks. Performance of PS 3 also can be valuable in determining the nature of the problem when a monitoring system fails PS 2.

Calibration Drift

The calibration drift test follows the procedures in PS 2. The data and drift specifications are, however, in units of percent oxygen or percent carbon dioxide. The calibration drift limit is 0.5% O₂ or CO₂.

Relative Accuracy

A relative accuracy test is not necessary for diluent O₂ or CO₂ monitors tested under PS 2. For other O₂ or CO₂ monitoring systems, Reference Method 3 of 40 CFR 60 Appendix A is used. Due to the inaccuracies associated with the manual ORSAT method, it is recommended that Reference Method 3A (instrumental method) be used.

The relative accuracy specification is 20 percent of the mean value of the reference method test data or 1.0 percent O₂ or CO₂, whichever is greater.

401.1.5 Performance Specification Tests for Other Pollutant Gases

The performance specifications for most monitors for other gases refer back to PS 2 requirements and procedures. Performance Specification 2 is written specifically for SO₂ and NO_x monitors, although the principles contained in it have been more widely applied. The applicable regulations and performance specification for the gas being monitored should be consulted for any variations of PS 2 and the specific CD and RA limits.

401.2 CERTIFICATION TESTS FOR OPACITY MONITORS

There are three means of measuring the visible density, or opacity, of emissions from a source. The visible emission observation technique, EPA Reference

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Method 9, has been extensively used for plume evaluation and many enforcement actions, however, it is not designed to be a long term monitoring method. Also, observations on cloudy days, at night, etc. can be problematic.

Two instrumental methods that can be used to monitor emissions are the LIDAR technique and transmissometry. The LIDAR technique, EPA Reference Method 9A, uses the backscatter of laser light to measure the plume particulate matter. It is an open path technique and has the advantage that it can be operated from outside the plant property as an enforcement tool. However, as a stack monitor, it is difficult to implement, being subject to many interferences, as are most open path techniques, and is expensive to purchase and operate. LIDARs also require highly trained and experienced personnel to operate.

Lidar

The third opacity monitoring technique, transmissometry, is relatively straightforward and economical. A transmissometer measures the attenuation of light across the stack by interception by particulate. A transmissometer can be installed in various points of the stack or ducts and the data readily corrected to stack exit conditions.

Transmisso- metry

Transmittance, opacity, and optical density are all terms to say essentially the same thing - the attenuation of light intensity.

$$\% \text{Transmittance} = 100 - \% \text{Opacity}$$

or in fractional terms:

$$\text{Transmittance} = 1.0 - \text{Opacity}$$

Light Attenuation

Transmittance is the fraction of light that is transmitted through an optical medium of interest. Opacity, on the other hand, is the light that is attenuated by the optical medium of interest. In a more rigorous fashion, the Bouguer expression describes transmittance as:

$$T = \frac{I}{I_0} = e^{-naQl}$$

where: I = light intensity after passing through the flue gas

I_0 = reference light intensity

n = number concentration of particulate

a = projected cross section of a particle

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Optical Density

Q = particle extinction coefficient
 l = light path length through the flue gas

The opacity monitoring system is designed to determine the transmittance from two measurements: 1) the reference measurement, I_o , typically a portion of the light split from the source by a beam splitter; and 2) the intensity of light after it has passed through the flue gas, I . The ratio of light intensities gives the fractional transmittance, from which the opacity can be calculated.

For many calculations optical density is the appropriate expression for light attenuation⁸. The optical density is directly proportional to the particle concentration (c) and single pass pathlength (l) at the monitor (l_i) and at the exit (l_x):

$$D = \log 1/(1 - \text{opacity}) = A_E c l$$

or for double pass instruments:

$$D_i = \log 1/(1 - \text{opacity}_x) = A_E c 2l_i$$

where: A_E = the specific mass extinction (m^2/g), a function of the particle scattering characteristics, volume, and density. For most proposed, A_E is assumed to be constant.

The antilog of the equation can be used to express the opacity in terms of optical density as follows:

$$\text{Op} = 1.0 - 10^{-D}$$

401.2.1 Preliminary Tests and Adjustments

Laboratory Tests

Before installing the monitor, a number of preliminary tests and adjustments are necessary. These procedures can be conducted at the manufacturer or at the facility before installing the system on the stack. The procedures include adjusting the system to properly read the simulated zero and span, conducting the calibration error test, and conducting the response time test. Additional field tests are conducted after the monitor has been installed on the stack (Table 401.3).

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Table 401.3 Performance Specifications for Test Procedures

Parameter	Specifications
<u>Laboratory Tests</u>	
Calibration Error	$\leq 3\%$ Opacity
Response Time	≤ 10 seconds
<u>Field Tests</u>	
Conditioning Period	168 hours
Operational Test Period	168 hours
Zero Drift (24 h)	$\leq 2\%$ Opacity
Calibration Drift (24 h)	$\leq 2\%$ Opacity
Data Recorder Resolution	$\leq 0.5\%$ Opacity

Instrument Preparation

For these tests and adjustments the monitor is set up in a laboratory, control room, or other reasonably clean and convenient environment (Figure 401.6). The transceiver and reflector assemblies are set up, separated by a distance equivalent to which they will be separated when installed on the stack or duct (including the flange lengths). This setup should mimic the manner in which the monitor will be set up on the stack or duct.

The first adjustment to the system is to produce an output of the analyzer correlated to the stack exit opacity. This is usually accomplished by adjusting calibration switches or potentiometers.

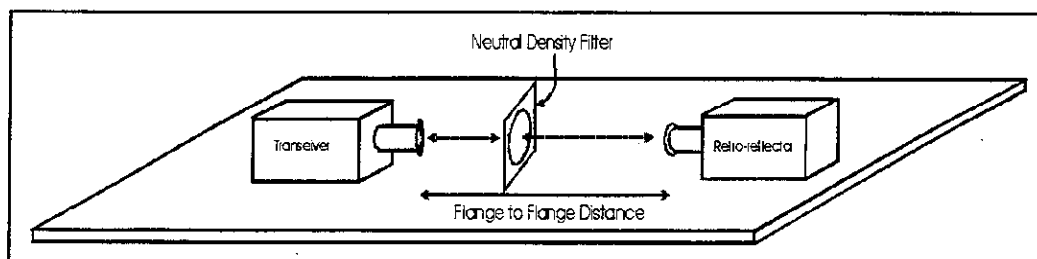


Figure 401.6 Laboratory Arrangement for Transmissometer Tests

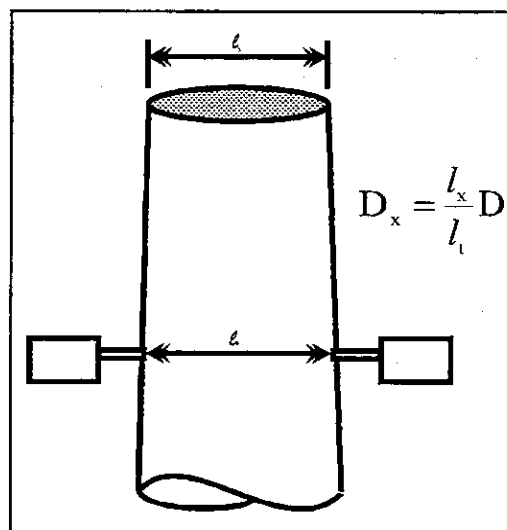
Bench Tests

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Pathlength Correction

Visible emissions regulations require measurement of the opacity of emissions at the stack exit; however, transmissometers are installed further down in the stack or duct. To obtain consistent readings between the transmissometer and EPA Reference Method 9, the transmissometer data must be corrected for the difference in pathlength between the stack exit and the monitor location (Figure 401.7).

The flue gas at the outlet of a tapered stack is not compressed. Instead, the velocity increases so that the particulate matter concentration and the volumetric flow rate will be the same at both locations. The important variable then in determining the optical density at each location is the pathlength. If the equation for optical density at the exit (D_x) is divided by the equation for optical density at the monitor location (D_t), the ratio of the pathlengths will equal the ratio of the optical densities.



**Figure 401.7 Stack Exit
Correlation**

$$D_x = (l_x / l_t) D_t$$

Note that, for a double pass instrument, the monitor pathlength is twice the diameter of the stack; therefore, for a double pass instrument the optical density correlation would be:

$$D_x = (l_x / 2l_t) D_t$$

or:

$$\text{Opacity}_x = 1 - (1 - \text{Opacity}_t)^{l_x / 2l_t}$$

Another point to remember is that the transmissometer pathlength (l_t) is the length over which the flue gas is measured, bounded by the walls of the stack, rather than the flange to flange distance.

Next, the instrument is turned on and aligned using the alignment sight. The alignment of the retroreflector (or receiver unit) should also be adjusted until the maximum response is achieved. Since the monitor is measuring clean laboratory air, the instrument should read zero opacity.

The system simulated zero should now be adjusted so that it corresponds to the zero from the laboratory air path. In some systems this requires adjustment of an iris on the zero mirror. On other systems electronic adjustments are required.

After the zero adjustments are made, the internal upscale calibration value is determined. This usually involves actuating the calibration cycle and noting the signal produced by the monitor. The value of the filter must be in the range required by the particular application.

Calibration Error Test

After the transmissometer has been adjusted, the calibration error test is conducted (using the same setup as for the adjustments). The test is conducted by placing neutral density filters in the analysis beam path. Neutral density filters are filters that will attenuate the light without changing the color spectrum. The filters should be placed at the midpoint between the transceiver and the retroreflector to simulate a measurement of particulate in the analysis path.

The filters in this test are required to have values within certain ranges specified in Performance Specification 1 (Table 401.4). The filters must be calibrated against a laboratory spectrophotometer or certified as having been calibrated by the vendor or an independent laboratory. Three filters are specified: low-, mid-, and high-range. The span value and filter values correspond to opacity values as observed at the stack exit. Therefore, it is necessary to account for the stack exit correlation factor when selecting the filters.

The actual calibration error test is simply a matter of alternately measuring the response of the monitor using the selected attenuator filters. First the low-range filter is placed midway between the transceiver and retroreflector (Figure 401.6) to obtain a monitor reading; the data is recorded on a data record form (example in Appendix A). Next the mid-range filter is used, then the high-range filter. The procedure is repeated until five nonconsecutive readings have been made using each attenuation filter.

After the 15 measurements are made, the calibration error is calculated using equations similar to those used for relative accuracy determination of gas monitors. The calibration error is required to be less than three percent opacity expressed as the sum of the absolute value of the mean difference and the confidence coefficient.

Certified Neutral Density Filters

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Calibration Error Test Data					
Person Conducting Test		Sam	Analyzer Manufacturer		Sam's CEMs
Affiliation		Sam's CEMs	Model/Serial Number		445.52
Date		4/10/1990	Location		Acme Power Plant
Monitor Pathlength L1		4.48 m	Emission Outlet Pathlength L2		7.32m
Monitoring System Output Pathlength Corrected?			<input checked="" type="radio"/> Yes	<input type="radio"/> No	
Instrument Span Value		80% Opacity			
Calibrated Neutral Density Filter Values:					
Actual Optical Density (Opacity)			Path Adjusted Optical Density (Opacity)		
Low-Range 0.07 (15%)			Low-Range 0.114 (23.1%)		
Mid-Range 0.20 (37%)			Mid-Range 0.327 (52.4%)		
High-Range 0.40 (60%)			High-Range 0.654 (77.8%)		
Run Number	Calibration Filter Value (Path Adjusted Percent Opacity)	Instrument Reading (Percent Opacity)	Arithmetic Difference (Percent Opacity)		
			Low	Mid	High
1 - Low	23.1	23.5	0.4		
2 - Mid	52.9	52.5		-0.4	
3 - High	77.8	77.0			-0.8
4 - Low	23.1	23.0	-0.1		
5 - Mid	52.9	52.2		-0.7	
6 - High	77.8	77.2			-0.6
7 - Low	23.1	23.5	0.4		
8 - Mid	52.9	52.6		-0.3	
9 - High	77.8	77.5			-0.3
10 - Low	23.1	23.2	0.1		
11 - Mid	52.9	52.8		-0.1	
12 - High	77.8	77.5			-0.3
13 - Low	23.1	23.2	0.1		
14 - Mid	52.9	52.5		-0.4	
15 - High	77.8	77.2			-0.6
Arithmetic Mean			0.18	-0.38	-0.52
Confidence Coefficient			0.269	0.269	0.269
Calibration Error			0.45	0.65	0.74

Figure 401.8 Example Calibration Error Determination

Example Calibration Error Calculation

The data in Figure 401.8 represents hypothetical data obtained by using three filters. The actual certified filter opacities were 15, 37, and 60% opacity. Adjusting these values for stack-exit conditions, $lt/lx = 4.48/7.32 = 0.612$, the path adjusted filter values are 23.1, 52.9, and 77.8% opacity respectively.

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Table 401.4 Required Calibration Attenuator Values for Low-, Mid-, and High-Range Filters. Equivalent Opacity in Parentheses.

Span Value (% Opacity)	Calibrated Attenuator Optical Density		
	Low-Range	Mid-Range	High-Range
40	0.05 (11)	0.1 (20)	0.2 (37)
50	0.1 (20)	0.2 (37)	0.3 (50)
60	0.1 (20)	0.2 (37)	0.3 (50)
70	0.1 (20)	0.3 (50)	0.4 (60)
80	0.1 (20)	0.3 (50)	0.6 (75)
90	0.1 (20)	0.4 (60)	0.7 (80)
100	0.1 (20)	0.4 (60)	0.9 (87.5)

In the calibration error test, an error difference is calculated for each filter. The mean of the differences, standard deviation, and confidence coefficient are then calculated. The details of the calculation of the low-range are as follows:

Run No.	x_i	x_i^2
1	+0.4	0.16
4	-0.1	0.01
7	+0.4	0.16
10	+0.1	0.01
13	+0.1	0.01

$$\sum x_i = 0.9$$

$$\sum x_i^2 = 0.35$$

$$\bar{x} = \frac{\sum x_i}{n} = \frac{0.9}{5} = 0.18$$

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$$S_d = \left[\frac{Sx_i^2 - \frac{(Sx_i)^2}{n}}{n-1} \right]^{1/2} = \left[\frac{0.35 - \frac{0.9^2}{5}}{5-1} \right]^{1/2} = 0.217$$

$$CC = t_{0.975} \frac{S_d}{\sqrt{n}} = 2.776 \frac{0.217}{\sqrt{5}} = 0.269$$

$$CE = |\bar{x}| + |CC| = 0.18 + 0.269 = 0.45$$

The calibration error, which must meet the $\leq 3\%$ requirement, is the sum of the mean difference and the confidence coefficient. As can be seen from this test, the monitor passes the calibration error test.

Response Time Test

Response time is the time it takes the opacity monitoring system to display, on the data recorder, 95% of a step change in opacity. The response time test used to determine this value requires that a high-range attenuator be placed in the analysis beam. The time it takes the recorder to go from its zero value to 95% of the attenuator value is measured and recorded as the upscale response time (an example data sheet is in Appendix A). After the attenuator has reached its full value, it is removed. The time it takes for the instrument to go to a value of 5% of the value is recorded as the downscale response time. This procedure is repeated five times. All ten response time values are then averaged to obtain the instrument response time. The average must be less than ten seconds.

401.2.2 Field Tests

After the monitor has been demonstrated to operate correctly in a laboratory setting, it is installed on the stack or duct. Generally, by the time the monitor is ready to install, the support infrastructure: electrical connections, access platforms, data cables, etc; has also been completed. The ability to at least turn on

95% Step
Change

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the blowers to protect the windows and optics should be in place when the instrument is installed.

Installation

The first step in the installation is to physically attach the instrument to the stack and turn it on. Preliminary alignments can be made while the unit is being attached so that when turned on, the beam strikes the detector or retroreflector close to where it should.

An optical alignment sight or telescope is used to adjust the transceiver and retroreflector assemblies. Ideally, this is done when the source is not operating and no particulate matter is in the optical path. If this is the case, the simulated zero can be checked against an across-the-stack zero. The results of this simulated zero check should match the results when the instrument was checked in the laboratory.

If it is not possible to install the monitor when the facility is down, the alignment and zero adjustments should be verified at the first available opportunity. This could be during a scheduled maintenance period, or when a malfunction has forced the facility out of service. Care should be taken that the stack is truly clear. Even when the facility is off line, the fans may be operating or naturally induced drafts may entrain particles remaining in the system.

After the facility has started up the alignment should be rechecked. Thermal expansion of the heated stack walls and operational vibration may cause misalignment or other problems that weren't apparent before startup. The instrument should be realigned if it becomes misaligned under operating conditions.

Conditioning Period

The next step is to confirm that the monitor will continue to operate and maintain its alignment during operation. This means that the monitor must operate without requiring unscheduled maintenance or repairs for at least 168 hours (1 week). During this period the zero and upscale calibration checks are conducted each day and the optical alignment is rechecked at the end of the period.

The monitor must operate, i.e. analyze the flue gas opacity, for the entire 168 hours. If the facility breaks down or operation is intermittent, the times and dates

Alignment

168 Hours

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168 Hours

Zero and Upscale Drift

of down time must be recorded. The conditioning period is stopped while the unit is offline; but it can be restarted after the source resumes operation.

The required conditioning period serves several purposes. It provides a shake-down period for the system components and gives the operator a chance to become familiar with the system. The conditioning period applies only to opacity monitors (PS 1), it was not included in other performance specifications (PS 2, PS 3, etc.).

Operational Test Period

In the operational test period the monitor must demonstrate that it can hold its calibration for an extended period of time. During the 168 hours of the operational test period, data are taken so that the zero drift and upscale drift can be calculated. The mean drift values must be less than 2% opacity for each. An example zero and calibration drift test data record form is in Appendix A of this manual.

A calibration value of up to 10% may be used in place of the simulated zero calibration value. The upscale value will depend upon the full scale span value of the monitor. The upscale calibration value attenuator must be greater than or equal to the applicable opacity standard, but less than or equal to one-half the applicable instrument span value, i.e. for a source with a standard of 20% opacity and a monitor span value of 60% opacity, an upscale attenuator equivalent to 25% opacity might be chosen.

The operational test period does not have to immediately follow the conditioning period (although they cannot be conducted concurrently), but the plant must be operating and the instrument monitoring flue gas for the entire 168 hours.

If the monitor fails either the zero or upscale drift test, the problem must be corrected and the 168 hour operational test period repeated. Depending upon the nature of the corrective action required (i.e. if the corrections may affect the design specifications, calibration error test, or the response time test), more indepth retesting may be required.

The test is carried out by recording, at initiation of the test, initial zero and upscale readings. Twenty-four hours later the readings are taken again. This is continued for at least seven days (168 hours) or until seven 24 hour readings can be obtained. The instrument may be adjusted during the test, but only after

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taking data. Similarly, for window cleaning, the data must be taken before cleaning. If no adjustments are made, the final readings for a 24 hour period become the initial reading for the next period. Otherwise, a new initial reading is made after the adjustments are made. The instrument can be adjusted after making the final zero reading (before making the upscale reading) since the zero drift is to be subtracted from the calibration drift before the data is averaged.

The upscale calibration drift test is conducted alongside the zero drift test. After the zero reading is obtained at the end of the 24 hour period, the upscale attenuator is moved into place and the upscale reading recorded. As with the zero test, the final upscale reading becomes the initial reading for the next 24 hour period unless the instrument upscale is adjusted.

The zero drift is calculated by subtracting the final reading from the initial reading for each 24 hour period. At the end of the test calculate the arithmetic mean, standard deviation, and confidence coefficient using the same equations as the calibration error calculations. The 24 hour zero drift value to be reported as the result of the test is the sum of the absolute value of the mean and the absolute value of the confidence coefficient.

The upscale calibration drift is calculated in the same manner, except that the zero drift is subtracted from the 24 hour upscale drift values.

During the operational test period, if either the zero or upscale attenuator readings drift by more than the 24 hour drift specification ($\pm 2\%$ opacity), either during a 24 hour period or cumulatively, adjustments and cleaning must be performed.

Performance Specification 1 requires that uncompensated reading must be obtained for the operational test period zero and calibration drift tests. Many instruments provide the data in terms of values compensated for automatically obtained zero and calibration drift. All instruments must provide a means of obtaining the uncompensated readings. Often this will require a manual override of the automatic systems. Obtaining the required data may, therefore, require day-to-day attention of an instrument operator.

401.3 CERTIFICATION TESTS FOR RATE MONITORS

Continuous rate (stack flow) monitors are sometimes required by NSPS and locally required monitoring systems; however, they are an integral part of moni-

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toring systems used by sources required to meet the Acid Rain Program requirements. The following is a discussion of the NSPS requirements contained in Performance Specification 6 of 40 CFR 60 Appendix B. The additional requirements of the Acid Rain Program will be discussed in Section 403.

Traditionally, NSPS sources have been required to report their emissions in terms of parts-per-million (ppm) or mass per unit input (ng/J); in either case a rate monitor is not an essential part of the monitoring system. A rate monitor is needed to incorporate the volumetric flow data with the pollutant concentration data if the source must report emissions in terms of mass per time (kg/h).

401.3.1 Calibration Drift Tests

Since rate monitors typically include analyzers for several measurements, the calibration drift must be determined separately for each analyzer in terms of its specific measurement. The calibration for each analyzer used for the measurement of flow rate, except a temperature analyzer, is not to drift or deviate from either of its reference values by more than three percent of 1.25 times the average potential absolute value for that measurement [i.e. an instrument measuring velocity at 27 m/s must not drift by more than 1 m/s ($27 \text{ m/s} \times 1.25 \times 0.03$)]. For a temperature analyzer, the specification is 1.5 percent of 1.25 times the average potential absolute temperature [i.e. a temperature sensor measuring 350°C must not drift by more than 12°C ($(350^\circ\text{C} + 273\text{K}) \times 1.25 \times 0.015$)]. The calibration drift specifications for analyzers associated with the rate monitor in a monitoring system for which other performance specifications have been established (e.g. PS 2 for SO₂ and NO_x) is wrapped up in the applicable PS.

The calibration drift test for the rate monitor should be conducted at levels analogous to the levels at which the associated pollutant calibration drift test was conducted. The low level should be between zero and 20% of the high-level value. The high level value is a level between 1.25 and 2 times the average potential value for that parameter. The high-level calibration drift measurement point should be 50 to 100% of the high-level value.

The tests are conducted by introducing an electrical reference signal to the transducer or a known air pressure into a velocity pressure type instrument. The reference signal or known pressure don't have to be certified, however, they must be known and constant. The monitor response and reference values are recorded and the monitor response subtracted from the reference value. The calibration drift is then calculated following the procedures for gas monitors in PS 2.

$$CD_R = V \times 1.25 \times 0.03$$

$$CD_T = T \times 1.25 \times 0.015$$

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401.3.2 Relative Accuracy Test Procedures

As with other parameters, the relative accuracy test is a comparison between the results from the monitoring system and a reference method test. The relative accuracy test for a rate monitor follows the same procedures as a gas monitor in PS 2. For the rate monitor, the reference method to be used is EPA Reference Method 2 (or 2A, 2B, 2C, or 2D); other reference methods can be used if specified in the applicable subpart or in the permit.

401.4 PERFORMANCE SPECIFICATION TEST REPORT

The purpose of the test report is to document the tests performed and to present the test result data. The report should be well organized and complete so as to be a usable document that can be referred to if problems develop at the facility. Much of the data presented should be presented in tabular form to facilitate reading and understanding of the report. Sufficient information should be in the report; including information concerning the monitoring system, reference methods, test procedures, and results, such that someone could pick up the report and recalculate any of the results.

At a minimum, the calibration drift and relative accuracy data (or alternate RA procedure) should be reported in a summary table. A check should be made with the appropriate regional EPA office, or state or local agency for any additional requirements. The data sheets from the test, calculations, charts and records of CEM responses, cylinder gas concentration certifications, and calibration gas cell certifications should also be submitted with the report.

The report should contain:

- I. Executive Summary - presenting a summary of the tests and results. A supervisor or reviewer should be able to get an overview of the test within five to ten minutes by reading the executive summary.
- II. General Information -
 - a. description of the facility and unit being monitored
 - b. person(s) responsible for operational and conditioning test periods
 - c. instrument manufacturer
 - d. instrument model and serial numbers
 - e. month/year instrument was manufactured

Data Tables

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- f. schematic of monitoring system measurement path for path in-situ monitors, sampling point for point in-situ and extractive monitoring systems (include distance to disturbances)
- g. pathlength (meters or feet) for path in-situ monitors
- h. emission outlet pathlength (meters or feet)
- i. system span value
- j. upscale calibration value
- k. calibration attenuator values for opacity monitors; low and high level calibration points for other systems

III. Design Specification Test Results (Opacity only)

- a. peak spectral response
- b. mean spectral response
- c. response above 700 nm, percent of peak response
- d. response below 400 nm, percent of peak response
- e. total angle of view, degrees
- f. total angle of projection, degrees
- g. results of optical alignment test
- h. serial number and month/year of manufacture of unit actually tested to show design conformance

IV. Performance Specification Test

- | <u>Opacity</u> | <u>Other Systems</u> |
|----------------------------------|-----------------------------------|
| a. calibration error, high-range | relative accuracy test results |
| b. calibration error, mid-range | |
| c. calibration error, low-range | |
| d. response time | |
| e. 24 hour zero drift | low-value calibration drift test |
| f. 24 hour calibration drift | high-value calibration drift test |
| g. lens cleaning, clock time | |
| h. optical alignment adjustments | |

V. Test Period Completion Statements

- a. statement that the conditioning test period had been successfully completed, include the time periods when the test was conducted and any significant events that occurred
- b. statement that the operational test period had been successfully completed, include the time periods when the test was conducted and any significant events that occurred

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- VI. Appendix - provide the data tabulations and calculations
- a. data sheets, computer printouts, and strip charts from the test
 - b. equations used and example calculations
 - c. cylinder gas/calibration cell concentrations and certifications
 - d. copy of the test method used if a standard test was not used or significant modifications of the method were employed. Include an explanation of why the standard method could not be used.

Some agencies or programs have additional report requirements or special formats and tables. During the pretest conference the report format should be discussed and finalized. If the design specifications were certified by the vendor, the certificate of conformance must be included in the report. Also, if the laboratory tests for response time and calibration error were conducted by the vendor or a consultant, those results should also be included. The original data sheets, printouts, stripcharts, and data forms should be signed and dated during the test; the agency observer should also initial them during the test.

Vendor
Certifications
and Results

Original Data

402 AUDITS OF CEM SYSTEMS

Once a monitoring system has been installed and certified, it is expected to provide valid data that is accurate and precise within specified tolerance levels. One aspect of the quality assurance program that determines whether or not those limits are, in fact, being met is the audit. An audit is a review of the CEM system and its data quality. By definition, an audit is conducted by an independent party. Typically this is either an independent auditor within the facility, a contracted source testing consultant, or an air quality agency inspector.

Three basic types of audits can be applied to continuous emission monitoring systems: 1) the systems audit, 2) the agency oversight audit, and 3) the performance audit. The systems audit is a qualitative evaluation of the entire monitoring system. This is normally not a hands-on audit, but an evaluation of the system operation and management practices. The agency audit is conducted by an oversight air quality agency (such as the California Air Resources Board, or one of the air pollution control/air quality management districts). It is very similar to the systems audit, but is specifically conducted by the agency and focuses on compliance related issues. The performance audit is a quantitative audit that tests the output of the system by employing reference methods and certified audit materials.

Systems
Audits,
Oversight
Audits,
Performance
Audits

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Configuration and Condition Operation Records

402.1 SYSTEMS AUDIT PROCEDURES

A CEM system audit constitutes a formal, in-depth examination of the entire monitoring program. There are several phases of the systems audit including: 1) a physical tour of the CEM installation to review the system configuration and condition; 2) an evaluation of the CEM system operational status; and 3) a review of system output, data, and records.

The systems audit can be an involved process requiring considerable time and effort. The auditor must have good technical abilities, interpersonal skills, and detective "sleuthing" capabilities. In the course of the audit the auditor will be called upon to meet with facility personnel from the unit operator and the CEM technician to plant managers and corporate vice presidents and directors. The systems audit will frequently be seen as intrusive, especially by corporate management, but a well conducted systems audit will give all concerned an indication of how well the CEM program is operating and give confidence in the quality of data generated by the system.^{9,10}

402.1.1 The Initial Briefing

An initial briefing introduces the auditor and plant personnel and addresses the purposes and extent of the audit. At this stage the administrative details are arranged and access to files, personnel, and materials is clarified. The initial briefing is important in setting the stage for the rest of the audit.

402.1.2 The CEM System Site Tour

A tour of the CEM system and installation should familiarize the auditor with the system and its operation. All aspects of the installation, from probe to data output and file storage, should be inspected. In addition, before arriving at the facility, the auditor should have reviewed the agency files and records concerning the facility and monitor. During the tour the auditor will inspect the installation of the monitor on the stack or duct, the CEM shelter, and the control room. In all likelihood, the majority of the time will be spent in the CEM shelter.

System Care

In the CEM shelter, the auditor should observe that the system appears to be well cared for. If wires and tubing are neatly wrapped and their course well laid out, there is a higher probability that the monitor is functioning properly. The auditor should inspect the system maintenance and instrument logs and the facility quality assurance manual. These should appear to be routinely used and up to date.

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402.1.3 Operational Evaluation

Both the plant and the CEM should be operating normally during the audit. The plant operator and/or instrument technician should be able to answer questions and demonstrate the features and operation of the system.

During the systems audit a checklist (see Appendix A) helps to guide the auditor through the process. Checklists should form a framework for the inspection, however, they should be flexible and the auditor should not be constrained by the checklist. Rote adherence to a lengthy checklist does not reflect that the auditor is knowledgeable about the facility, process, or monitors.

A common practice is to follow the flow of flue gas in the inspection, starting at the CEM installation on the stack or duct. At the installation point the monitoring equipment should appear to be the same equipment as was certified. However, it should also be obvious that plant personnel routinely visit the site to perform maintenance. If possible, it is a good practice to observe a calibration cycle and probe blowback cycle at the installation site. For path monitors, such as opacity monitors, that have an alignment sight, the auditor should check the alignment.

The operator should be asked to perform a system calibration. The auditor should note how familiar the operator is with the procedures and how the results are annotated on the strip-chart and computer records and in the log books. If the control room is separate from the CEM shelter, the information observed in the shelter should be confirmed in the control room.

402.1.4 Review of Data and Records

The review of data files and records can take a considerable time; several hours, at least, depending on the complexity of the CEM installation and the format and quality of the data files. Documentation and records might include inspection sheets, logbooks, management reports, and test reports.

The auditor should review the CEM quality assurance plan for thoroughness and effectiveness. The QA plan can serve as a tool in conducting the review. The auditor should determine if the QC procedures are being conducted and request corroborating documents, if necessary. An effective QA plan is the crux of a well operating CEM system.

Checklists

QA Plan

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Logbooks

The logbooks should be a primary source of information about maintenance and operation of the monitors. There should be entries for frequency of maintenance, parts replacement, and any unusual occurrences. For gas monitors, the change-out dates for calibration cylinders and their gas concentrations should be recorded. For transmissometers, filter changes, window cleaning, lamp replacements, etc. should be recorded. If excessive maintenance appears to be required, a more thorough overhaul of the CEM system may be required. It has been documented¹¹ that transmissometer systems can operate with an availability of better than 97% of the time and gas monitor systems better than 90 - 95% availability. Unscheduled downtime greater than 5% should be investigated.

Records and Data

The EPA requires that a source retain data records for two years. Data for the past 30 days and maintenance records for the past quarter should be reviewed. If possible, the period of records reviewed should coincide with a period for which summary reports have been submitted. It is a good practice to concentrate the review on periods of excess emissions or monitor problems indicated by the reports. When reviewing the records the following should be noted:

- missing data
- unusually noisy or flat data
- inconsistent trends in readings
- annotations for monitor and source downtime
- annotations for exceedances
- printed fault or warning codes

Data should be coordinated between strip chart recordings and computer records. It should be confirmed that raw data files are retained by the computer and that these are not changed by calibrations, etc. The output files only should be modified by calibration changes.

402.1.5 Wrap-up and Reports

At the conclusion of the audit, a formal (or informal) meeting with facility personnel should be conducted to discuss the findings of the systems audit. If previous systems audits have been conducted, part of the discussion should address progress toward correcting issues from the previous audits.

A final systems audit report organizes and coordinates the information gathered in the audit in a usable manner. The report also serves as a record that can be referred to when follow-up inspections occur or for the next systems audit.

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402.2 AGENCY AUDITS

The primary focus of an agency audit is generally on compliance issues. Agency inspections can be conducted at various levels:

- Level I Excess Emissions Report review
- Level II CEM systems audit
- Level III Performance audit
- Level IV Relative accuracy testing

The Level I audit is generally conducted in the office as a review of data reporting. The Level III and IV reviews involve hands-on testing of the system. These audits may overlap with similar procedures conducted by the facility, or by contractors hired by the facility. However, the agency may conduct an independent audit to resolve specific compliance questions.

The EER review is a common quarterly agency procedure. These quarterly reports should be reviewed and reconciled with the startup, shutdown, and other emission excursions routinely reported by the source during the quarter (see chapter 500)

402.3 PERFORMANCE AUDITS

Performance audits are conducted on a regularly scheduled basis as part of a QA program such as that mandated by the EPA in 40 CFR 60 Appendix F for NSPS sources or 40 CFR 75 Appendix B for Acid Rain sources. A performance audit is a hands-on and independent assessment of the accuracy of the data reported by the CEM system. Each CEM must be audited at least once each calendar quarter. Successive quarterly audits must be at least two months apart.

The most frequently conducted performance audit is the cylinder gas audit (CGA). The CGA challenges the monitoring system with certified audit gases.

CGA

The relative accuracy test audit (RATA) is a more thorough performance audit. In a RATA test the data produced by the monitoring system are compared to a reference method test. This is essentially a repeat of the relative accuracy portion of the certification procedure.

RATA

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Table 402.1 Calibration Gas Certifications

Gas Type		Certification
SRM	Standard Reference Material	Prepared and sold by NIST
NTRM (CRM)	NIST Traceable Reference Material (takes the place of the Certified Reference Material)	Prepared by the gas vendor Referenced directly to a SRM Nominal Concentration within +/- 1% of an SRM concentration Analyzed after preparation and again 30 days after first analysis Two samples analyzed by an independent laboratory
GMIS	Gas Manufacturer's Intermediate Standard	Prepared by the gas vendor Referenced to a SRM or NTRM Nominal concentration 0.3 to 1.3 times the concentration of the SRM or NTRM Must be assayed three times over three months Assays must agree to within 1% Must be recertified every three months
Protocol 1 Gas		Prepared by the gas vendor Referenced to a SRM, NTRM, or GMIS Nominal concentration 0.3 to 1.3 times the concentration of the SRM, NTRM, or GMIS Assays must agree to within 1.5% Reactive gases must be reassayed after seven days

RAA

A step between the CGA and the RATA is the relative accuracy audit (RAA). The RAA test consists of a shortened RATA performance audit versus the reference method tests.

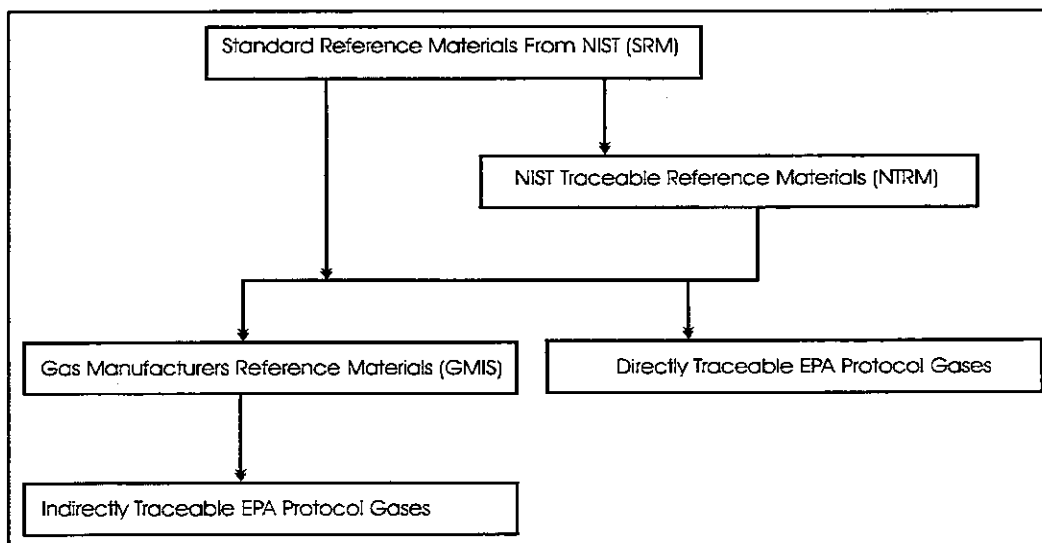


Figure 402.1 EPA Protocol Gas Traceability Hierarchy

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402.3.1 Audit Gases

Audit gases must be certified against National Institute of Standards and Technology (NIST) Standard Reference Materials (SRM) or other NIST-approved reference materials (Table 402.1). NIST SRMs can be used for the audits, however, those gases are extremely expensive and in limited supply. Therefore, other intermediate standards may be used.

EPA regulations define a gas traceable standard as one that has been compared and certified, either directly or via not more than one intermediate standard, to a primary standard, such as an SRM, or NTRM (Figure 402.1). The higher on the hierarchy, the more accurate and expensive the gas will be.

The EPA Protocol Gas procedures (revised in 1993) allow multicomponent gases. The manufacturing of these gases must eliminate, or adequately correct, cross-interference among the various components. Of particular concern are mixtures of SO₂, NO, and CO₂ where high concentrations of CO₂ can interfere with NO analyses.

402.3.2 Cylinder Gas Audits (CGA)

As mentioned above, the cylinder gas audit is the most frequently conducted performance audit procedure. A CGA is conducted by challenging the CEM system with two audit gases. One gas must be between 20 and 30 percent of the span and the other between 50 and 60 percent of the span for pollutant monitors. A diluent monitor uses a low level of five to eight percent CO₂ or four to six percent O₂ and a high level of 10 to 14 percent CO₂ and 8 to 12 percent O₂ (Table 402.2).

Table 402.2 Cylinder Gas Audit Concentration Ranges

Audit Point	Pollutant Monitors	Diluent Monitors	
		CO ₂	O ₂
1	20 to 30% of span value	5 to 8% by volume	4 to 6% by volume
2	50 to 60% of span value	10 to 14% by volume	8 to 12% by volume

NIST Approved Reference Material

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A CGA may be conducted in three of four calendar quarters, but in no more than three quarters in succession.

The monitor is challenged with each gas alternately three times. Sufficient time must be allowed for the reading to stabilize. (The audit readings must not be included with the facility emissions readings. The CEM system operator should place the system in an alternate mode during the audit.)

The difference between the actual, certified concentration of the audit gas and the monitor response is used to assess the accuracy of the CEM. For a CGA, the accuracy criteria (unless otherwise specified in the applicable subpart) is $\pm 15\%$ of the average audit value or ± 5 ppm, whichever is greater.

A CGA is a good procedure for routinely checking the function of a CEM system, however, the system operators and management should remember what the test is measuring and some of the pitfalls of the procedure. At its most basic, the CGA is not a completely independent measurement of CEM performance. It essentially checks the audit gas reading against the calibration gas (as opposed to RATA or RAA tests that employ a reference method test comparison). If the audit gas reading obtained on the analyzer differs widely from its certified value, it might indicate that the span gas has deteriorated or its tag value is incorrect. In such a case, analysis of the span gas and the audit gas on an independent analyzer may indicate the source of the difference.

Audit Gas Flow Rate

If using probe vent techniques of auditing, allowing excess audit gas to flow into the stack, an initial step in the process should be to determine the required gas flow rate to totally exclude the flue gas or ambient air without wasting expensive certified audit gas. The flow of audit gas can be increased slowly until a steady reading is reached, after which additional gas will not result in a change to the monitor reading. Once this flow rate has been established, it can be used for future audits.

The pressure evinced in this procedure should be noted. In future audits the pressure required to achieve the flow rate will give an idea of the condition of the coarse filter.

When applying audit gas to the probe, however, care must be taken to not overpressure the system. An overpressure may result in an erroneously high reading. This effect is most common if the audit gas is injected behind the coarse filter (for example; in a point in-situ monitor probe). If the filter has become plugged by

particulate the audit gas will pass through the filter with difficulty, resulting in high pressure in the measurement cell.

This effect can be readily diagnosed. When the audit gas is turned off the gas in the cell should rapidly be replaced by flue gas. If the system is slow to return to the stack gas concentration, plugging of the filter may be indicated.

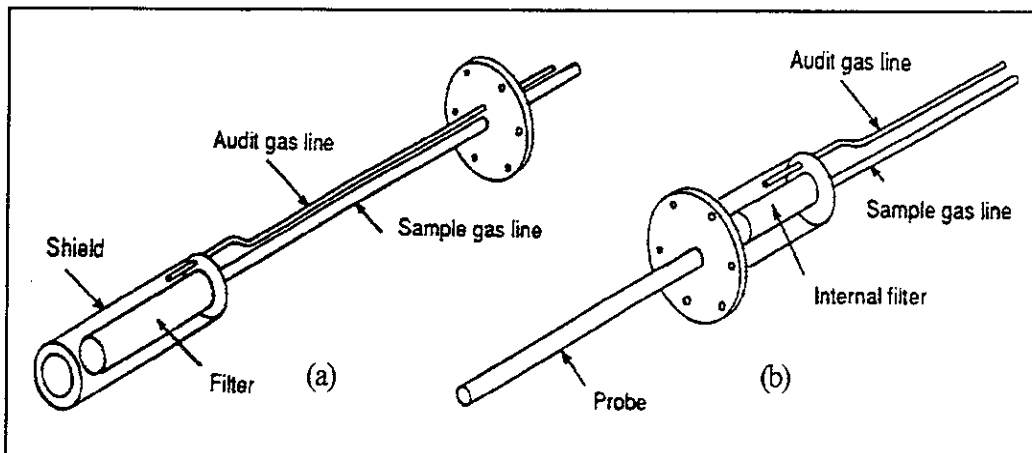
Source Level Extractive Systems

The audit gas should be presented to the monitoring system in a manner that, as nearly as possible, mimics the flue gas entering the system. The audit gas should flow through all filters, scrubbers, conditioners, etc. used during normal operation of the monitoring system and as much of the sample probe as possible.

From the standpoint of a complete audit, the injection of audit gas between an external coarse particulate filter and a probe shield (Figure 402.2a) is an excellent practice. However, it can require a significant quantity of audit gas to flush away all flue gas so only undiluted audit gas enters the sampling system. Less gas is required if the injection point is on the outside of an internal filter, into the annulus around the filter (Figure 402.2b), since the space is more effectively confined. Excess audit gas is vented through the probe.

The technique of flooding the probe with audit gas and venting the excess into the stack is referred to as the probe vent audit technique. Another technique, the

Probe Vent Technique



**Figure 402.2 Probe Audit Check Points for Extractive Probes,
a) External Filter, b) Internal Filter**

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External Atmospheric Vent Technique

external atmospheric vent technique (Figure 402.3), is used when the probe system cannot be flooded. The external atmospheric vent technique is a less desirable technique, but is acceptable if required. This technique injects the audit gas at the base of the probe and vents the excess to the atmosphere through a rotameter. The rotameter indicates that sufficient audit gas is being supplied to vent the excess. Care should be taken to be certain that the system is not pressurized when using either method.

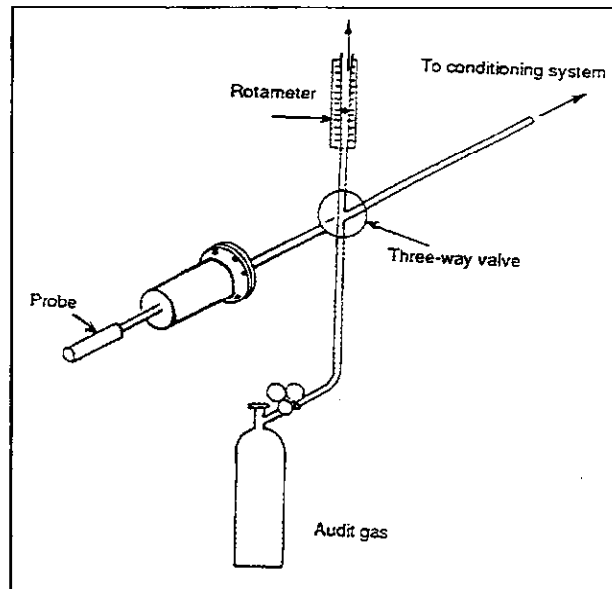


Figure 402.3 External Atmospheric Vent Audit Technique for Probes that Cannot be Flooded

Dilution Extractive Systems

A probe CGA is relatively easy for a dilution probe. As shown in Figure 402.4, the inner space of the probe can be readily flooded with gas. The space is generally fairly small and the demand of the system for gas is low, therefore the use of audit gas is relatively low (often about 50 - 100 cc/min).

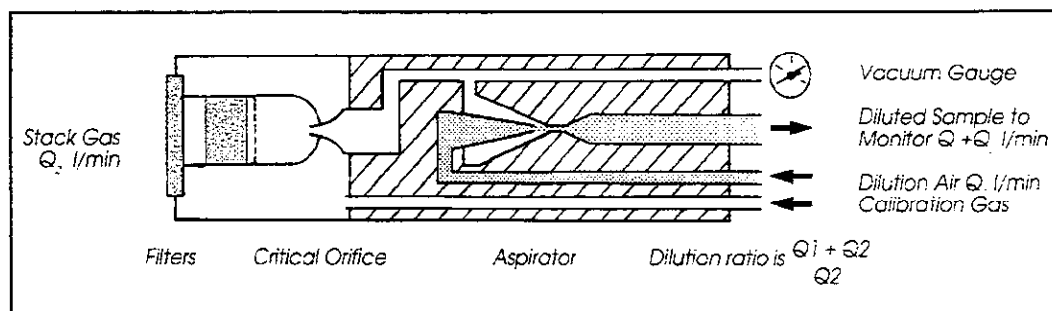


Figure 402.4 Dilution Extractive Probe

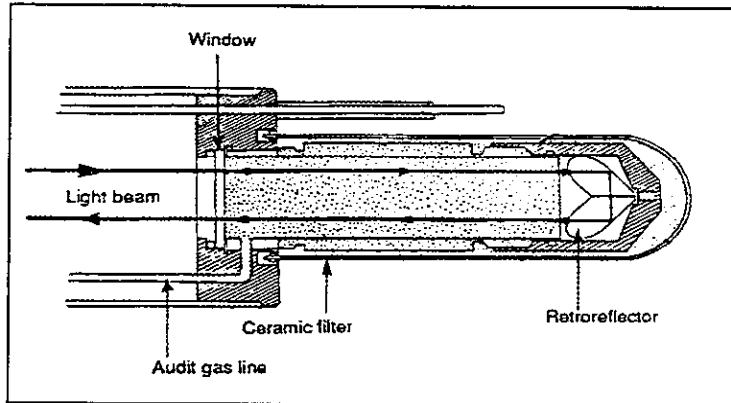


Figure 402.5 Point In-Situ Probe

Point In-Situ Systems

Performing a CGA on a point in-situ probe is similar to conducting a probe vent audit for an extractive system. The analysis chamber at the end of the probe is flooded with audit gas (Figure

402.5) with the excess, again, vented into the stack through the filter. Care needs to be taken to provide enough audit gas, but not so much that the system becomes pressurized.

Path In-Situ Systems

In a double-pass path in-situ monitor, a zero mirror is used to reflect the measurement light beam through a flow-through gas cell and back to the detector (Figure 402.6). The mirror isolates the transceiver from the stack, giving an

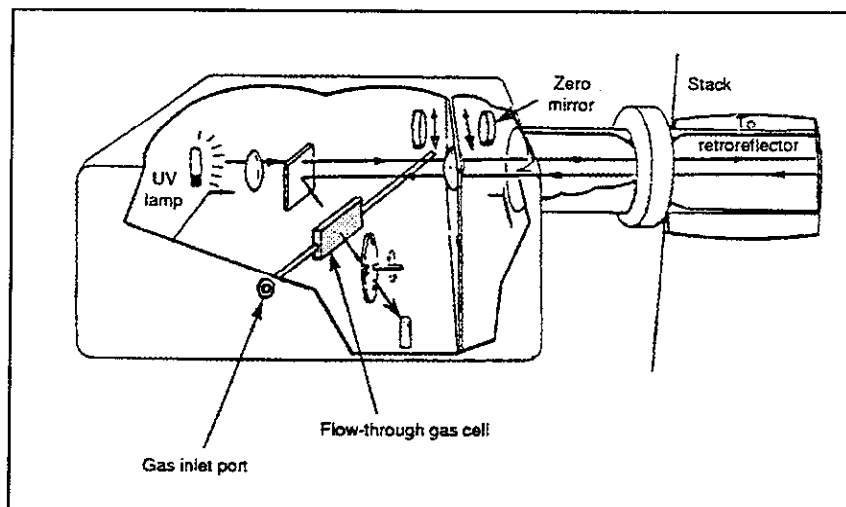


Figure 402.6 Cylinder Gas Audit for a Double-Pass In-Situ Path Analyzer

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Optical Depth

audit of the light source, most of the optics, and the detector; the retroreflector is not part of the system audited. The gas cell serves as a pseudo-stack. A drawback of this system is that the audit gas must be very high concentration to match the optical depth of the stack. For example, if the analyzer monitors gas at 600 ppm over a distance of 10 meters in the stack, the optical depth is $600 \times 10 = 6000$ ppm-m. To match that optical depth in a 1.0 cm (0.010 m) gas cell, the audit gas would have to be $6000 / 0.010 = 600,000$ ppm (60 %). Such high calibration gas concentrations are frequently unstable. Also, certified gases cannot be obtained at this level, limiting the usefulness of the path in-situ monitors, since they cannot meet certification and audit procedures.

Single-Pass Monitors

A meaningful cylinder gas audit of a single-pass monitor is more difficult to perform. The stack flue gas must be isolated from the monitor to conduct the audit on a clear stack. This can be done with a zero pipe, which closes to exclude the flue gas and is flushed with ambient air or calibration gas during a calibration or audit. Some analyzers use an auxiliary light source. This technique doesn't check the system in its normal operating configuration, and so is a poor substitute. There also are systems that use fiber optic light pipes to carry the light beam around the stack to the detector and use a flow-through gas cell to generate the upscale readings. This is probably one of the best solutions for a single-pass in-situ monitor. The fiber optic light pipe can also be used to carry a zero to the detector during normal operation.

402.3.3 Relative Accuracy Test Audits (RATA)

Sources that are subject to Appendix F of 40 CFR 60 are required to perform a relative accuracy test audit (RATA) at least one quarter out of four (i.e. once per year). A RATA test is a repeat of the relative accuracy portion of the CEM certification procedure (See Section 401.1.3).

Repeating the certification test is the ultimate audit technique. By repeating the certification of the monitor, a high degree of confidence in the results can be established. In addition to the direct comparison between the CEM results and an independent reference method test, Appendix F requires the analysis of an appropriate performance audit sample from the EPA. The EPA audit samples are readily available from the EPA and provide a measure of the accuracy and precision of the reference method test.

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402.3.4 Relative Accuracy Audits (RAA)

As an alternative to the cylinder gas audit (CGA), a source can conduct a relative accuracy audit (RAA) in three of four quarters. The fourth quarter still requires a RATA test. The RAA is a shortened RATA test. The RAA consists of three reference methods runs (rather than the nine required by the RATA). Like the RATA test, the RAA requires that an EPA audit sample be analyzed. The RAA calculations also differ somewhat from the RATA calculations by elimination of the confidence coefficient term. Compensating for the elimination of the confidence coefficient, the out-of-control criterion has been reduced from 20% in the RATA to 15% in the RAA.

Conducting an RAA is considerably more telling of the CEM's accuracy than a CGA, however, it is also considerably more time consuming and expensive. Reducing the number of test runs can save time, but not necessarily expense, relative to a RATA test. Much of the expense of a RATA test is associated with the stack test (i.e. travel, QA, reporting, etc. of the testing consultants). A few hours saved at the site generally does not save much money. The RAA is useful when its independent reference method test and external quality assurance measures are important.

402.3.5 Performance Audits of Opacity Monitoring Systems

Except for the daily zero and span check requirements, the EPA and most state and local agencies do not require a source operator to conduct tests or periodically assess the data quality of an opacity monitoring system. The facility is required to maintain the opacity monitor in proper operating condition and is expected to report reliable data, however, there are no tests equivalent to the RATA and CGM test required.

This is not to say that the transmissometer cannot or should not be audited. Agencies are given the latitude to conduct and/or require tests of the monitors whenever is appropriate.

A performance audit of a transmissometer consists of a calibration error analysis. This test gives a check of the calibration of the instrument and its linearity. On a new monitor, the calibration error test is usually conducted in a laboratory or at the manufacturer's facility on a benchtop, where the transceiver and retroreflector are setup at the flange-to-flange distance and filters placed in the measurement

Calibration
Error Test
Audit

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beam path. To conduct the audit, the transceiver is left on the stack and an audit device (or 'jig') is placed at the beam outlet of the instrument (Figure 402.7).

As in the initial calibration error test, three certified neutral density filters are analyzed five times (nonconsecutively). The calibration error is then calculated as the sum of the mean difference between the certified and measured value plus the confidence coefficient, using the same equations as in Section 401.2.1. The proper audit filters must be selected so their optical densities correlate to the appropriate stack exit opacities.

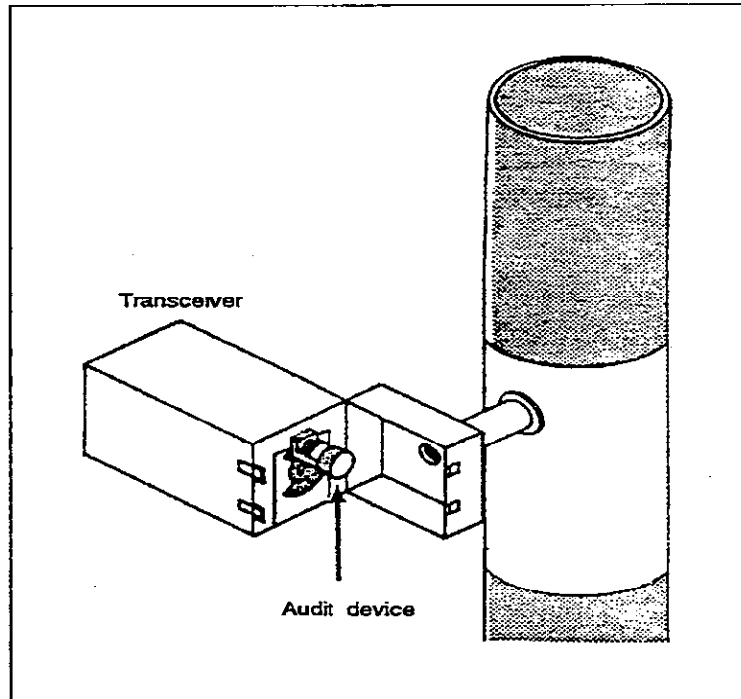


Figure 402.7 Transmissometer Audit Device Attached to Instrument

$$CE = |\bar{x}| + |CC|$$

$$CC = t_{0.975} \frac{S_d}{\sqrt{n}}$$

The transmissometer is viewed as having passed the performance audit if the calibration error for each filter is less than or equal to 3%.

The calibration error check of the performance audit does not check the absolute accuracy of the transmissometer system. There are many other factors involved in an opacity measurement, such as system alignment and the viability of the

cross stack zero. The procedures of the performance audit should, however, point out problems that might affect the opacity measurements.

The calibration error check using the audit jig is one of the best quality control procedures that can be incorporated into an opacity monitor quality assurance plan. Similarly, this audit can be conducted by the agency inspector to give additional confidence that the system is operating according to the design specifications.

402.3.6 Performance Audits of Rate (Flow) Monitors

Appendix F of 40 CFR 60 does not specifically address audits of the rate monitors, although they are incorporated, by inference, as part of the equipment to be audited and recertified. Section 2.1 of Appendix F defines the continuous emission monitoring system as "The total equipment required for the determination of a gas concentration or emission rate." For an NSPS source, the flow monitor is incorporated as part of the gas monitoring system for those systems that use them. The quality of data from the flow monitor becomes wrapped up in the data quality of the gas monitor.

For Title IV Acid Rain sources (Part 75), the rate monitor is specifically addressed. For flow monitors, one-level and three-level relative accuracy test audits are to be performed alternately (when the RATA tests are conducted semiannually). If only one RATA test is conducted each year, the three-level test must be conducted. The three-level test must be conducted at least once per year.

The flow audit consists of nine runs comparing the monitor readings with Reference Method 2 results. For the one-level flow audit, the readings are taken at one operating or load level: the normal process rate. For the three-level test the process is operated at three different operating levels with nine sample runs at each operating level.

Until 1 January 2000 the flow monitor must meet a relative accuracy standard of $\leq 15\%$ if semiannual tests are conducted. After that time the standard becomes $\leq 10\%$. To qualify to conduct annual tests only the flow monitor must meet $\leq 10\%$ or ± 0.46 m/s (± 1.5 fps) until 1 January 2000; or $\leq 7.5\%$ or ± 0.46 m/s (± 1.5 fps) after 1 January 2000.

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402.3.7 Out-of-Control Conditions

If a monitoring system does not meet the quality assurance criteria in Appendix F for calibration drift or relative accuracy, the system is deemed to be "out-of-control" (Table 402.3).

Table 402.3 Summary of Out-of-Control Conditions

Audit Type	Specification	Special Conditions
Calibration Drift	2 x PS drift specification	Five consecutive days
	4 x PS drift specification	Any one day
RATA	20% of mean value of RM test or 10% of the standard (whichever is greater)	
	15% of the standard	Standards between 130 and 86 ng/J
	20% of the standard	Standards below 86 ng/J
	10% of mean value of RM test or 5% of applicable standard (whichever is greater) (5 ppm for low level CO sources)	For CO monitors only
CGA	+/-15%	
RAA	+/-15% or +/-7.5% of the emission standard	

During the out-of-control period the CEM data may not be used in calculating emissions compliance, nor can it be counted towards meeting the minimum data availability as required and described in the applicable subpart. The data also cannot be counted or averaged as part of the minimum daily data requirements. System availability is defined as:

$$\text{System Availability} = \frac{\text{Total unit operating hours meeting QA criteria}}{\text{Total unit operating hours during the period}} \times 100$$

Periods of calibrations and audits are not generally exempt from the calculation of data availability. Therefore, calibrations and audits should be conducted

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Data Assessment Report

Period Ending Date 08 / 30 / 90 Reporting Year 90
 Company Name Acme Power, P.O. Box 911, Ricterville, CA 90210
 Plant Name Coal Burner Source Unit Number Coal Unit
 CEM System Manufacturer Sam's CEMs Model No. 445
 CEM System Serial Number 11456 CEM System Type (e.g. in-situ) dilution
 CEM Sampling Location (e.g. control device outlet) Coal unit stack
 CEM System Span Values, as per the applicable regulation: SO₂ 1000 ppm,
 NO_x _____ ppm, O₂ _____ percent, CO₂ _____ percent

I. Accuracy Assessment Results. (Complete A, B, or C below for each CEM system or for each pollutant and diluent analyzer, as applicable.) If the quarterly audit results show the CEM System to be out of control, report the results of both the quarterly audit and the audit following the corrective action showing the CEM System to be operating properly.

- A. Relative accuracy test audit (RATA) for SO₂ (e.g. SO₂ in ng/J)
1. Date of Audit 01 / 22 / 90
 2. Reference methods (RM) used 3 and 6 (e.g. methods 3 and 6)
 3. Average RM value 434.6 ng/J (e.g. ng/J, mg/dsm, or percent volume)
 4. Average CEM value 451.2 ng/J
 5. Absolute value of the mean difference (|d|) 16.73
 6. Confidence coefficient (|CC|) 27.30
 7. Percent relative accuracy (RA) 10.13 percent
 8. EPA performance audit results
 - a. Audit lot number (1) 0685 (2) 0685
 - b. Audit sample number (1) 3068 (2) 4012
 - c. Results (mg/dsm³) (1) 226.5 (2) 299.3
 - d. Actual value (mg/dsm³)* (1) 243.2 (2) 319.1
 - e. Relative error* (1) _____ (2) _____

- B. Cylinder gas audit (CGA) for SO₂ in ppm (e.g. SO₂ in ppm)
1. Date of audit 04 / 16 / 90
 2. Cylinder ID number 10132/AAL1035 Audit point 1 2016/AAL2012 Audit point 2
 3. Date of certification 02 / 05 / 90 02 / 05 / 90
 4. Type of certification CRM CRM (e.g. Protocol 1, CRM)
 5. Certified audit value 231 +/- 5 508 +/- 4 (e.g. ppm)
 6. CEM response value 222 494 (e.g. ppm)
 7. Accuracy 3.9 2.8 percent

* to be completed by the agency

Figure 402.8 Example Data Assessment Report (page 1)

Figure 402.9 Example Data Assessment Report (page 2)

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expeditiously. Availability specifications are commonly written into the source operating permits in addition to being in the regulations.

Out-of-control conditions exist for a calibration drift test if either the low-level or the high-level daily calibration check result exceeds twice the PS drift specification for five consecutive days or four times the drift specification for any one day. The beginning of the out-of-control period is the completion of the test that demonstrates the monitor does not meet the specifications; i.e. the beginning of the fifth consecutive daily CD check with CD in excess of twice the allowable limit or the completion of the daily CD check preceding the daily CD check that results in CD in excess of four times the allowable limit.⁴ The out-of-control period lasts until the instrument is repaired and retest demonstrates that the system now meets the criteria.

The system is also out-of-control if it fails a CGA, RAA, or RATA test. The out-of-control period begins with the completion of the failed audit and ends with the successful completion of a subsequent audit after corrective action has been taken.

402.4 DATA ASSESSMENT REPORTS

At the data reporting interval specified in the applicable regulation or permit (generally quarterly), a data assessment report must be filed for each CEM. The report must summarize the accuracy audits and the daily calibration drift results (Figure 402.8). An example form is contained in Appendix A of this manual.

At a minimum, the report must contain:

- Source owner / operator name and address.
- Identification and location of monitors.
- Manufacturer and model number of each monitor.
- Assessment of CEMs data accuracy and date of assessment as determined by a RATA, RAA, or CGA described in Appendix F of 40 CFR 60. If the accuracy audit showed the CEMs to be out-of-control, the operator must report both the audit results showing the unit out-of-control and the results following corrective action showing the instruments to be operating within specifications.
- Results from the EPA performance audit samples and the applicable reference method results.
- Summary of all corrective actions taken when the CEM system was determined to be out-of-control during calibration drift checks.

Summarize Audits and Calibration Drift Tests

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A review of the example DAR (Figures 402.8 and 402.9) shows that the source passed the RATA on 22 January 1990 with a relative accuracy of 10.13%. During the RATA the EPA samples were 6.9% and 6.2% low for samples 3068 and 4012, respectively.

The next quarter, a CGA was conducted on 16 April 1990. The monitor passed this test also with 3.9% and 2.8% accuracy for the low- and high-level tests, respectively.

On 23 July 1990 an RAA test was conducted. This time, however, the monitor failed the test. The test results showed an accuracy of 25.8%, outside the 15% limit for a CEM on a NSPS subpart Da electric steam generating unit and also outside of 7.5% of the standard. The analysis of the EPA samples indicates the analysis was properly conducted.

Starting at the time of the failed RAA, the CEM was rated out-of-control until it could be repaired and reaudited. It was out-of-control for eight days due to the failed RAA test. During these out-of-control times the CEM could not be used to report compliance data. This time also counts against the 95% CEM availability requirement.

Also on this example DAR is a report of the daily calibration drift checks. The unit was shown to be out of control due to drift in the days prior to the failed RAA, giving a preview that the RAA may fail. Since the lamp was not replaced until 31 July, finally fixing the problem, the unit continued to drift. The monitor was out of control for 12 days due to the excessive calibration drift, however, several of these days coincided with the RAA out-of-control period. During this later time, the unit was not available anyway because of the failed RAA. Thus, only four days are charged as out-of-control due to the excessive drift.

Missing from this DAR is the report of the reaudit showing the monitor back in control. The regulatory agency reviewing the DAR would not accept that the monitor was truly in control until the reaudit was reported.

403 ERROR PROPAGATION

An allowable error margin of 10, 15, or 20% may seem like a wide and easy target to hit during a certification or audit test. However, that allowance can be easily used up in the various errors associated with the tests. Some of the important sources of error can be:¹²

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CEM System:

- **Instrumentation (I_C)** - monitoring instruments are typically accurate to 1 or 2%
- **Sample System (S_C)** - the sampling system includes the probe, sample lines, and sample conditioning system. On a well run, well maintained system this can be on the order of 1%. However, it can easily exceed 10 to 15%, especially if the moisture condensation system removes SO_2 , NO_x , or other pollutants.
- **Human Error (H_C)** - this will include minor operator errors and effects of operator experience and training. In the example below, 2% is used.
- **Atmospheric Conditions (A)** - fluctuations in atmospheric pressure and temperature can effect a CEM system accuracy. In the example below, 2% is used.
- **Calibration Gas Quality (G_C)** - this is the uncertainty in the certification of the gas used to calibrate the monitor. EPA Protocol gases are certified to 2%.

Consultant Reference Method System:

- **Instruments (I_R)** - accuracy of the source test consultant's instruments. For this example they are chosen to be identical to the CEM system instruments, however, these instruments take a beating being transported between job sites and so may be less accurate. However, the consultant's instruments are generally tested, calibrated, and certified frequently. In the example below, 2% is used.
- **Sample System (S_R)** - the sampling system includes the probe, sample lines, and sample conditioning system. On a well run, well maintained system this can be on the order of 1%. However, it can easily exceed 10 to 15%, especially if the moisture condensation system removes SO_2 , NO_x , or other pollutants. Again, this system takes a beating being transported between job sites.

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Combining Errors

- **Human Error (H_R)** - this will include minor operator errors and effects of the source test consultant's experience and training. In the example below, 2% is again used as an approximate estimate.
- **Calibration Gas Quality (G_R)** - this is the uncertainty in the certification of the gas used to calibrate the equipment. EPA Protocol gases are certified to 2%.

The combined errors are not additive. A somewhat more sophisticated summation of the errors is required. The total error is calculated by calculating the square root of the sum of the squares of the individual errors (i.e. summing the variances).

$$\sqrt{I_C^2 + S_C^2 + H_C^2 + A^2 + G_C^2 + I_R^2 + S_R^2 + H_R^2 + G_R^2}$$

$$\sqrt{2^2 + 1^2 + 2^2 + 2^2 + 2^2 + 2^2 + 2^2 + 2^2 + 2^2} = 5.7\%$$

While none of the individual errors in this example are over 2%, the total error is 5.7%, meaning that the measured value, plus or minus 5.7%, will be achieved 95% of the time. It would be very easy to arrive at significantly greater error. For example, if a dilution probe (S_C) with $\pm 5\%$ error was used in the example, the total error would become $\pm 7.5\%$, the limit for qualifying for the relative accuracy test frequency incentive program.

The equations illustrate the importance of operator and tester training and experience and the importance of the quality assurance plan in maintaining the system at its peak performance. It also shows the importance in using high quality gases.

404 ACID RAIN PROGRAM MONITORING

As part of the Clean Air Act amendments of 1990, a program of controls and monitoring was instituted. The acid rain program restricts sulfur dioxide and nitrogen oxide emissions from "affected units", primarily utility boilers. Sulfur dioxide emissions are limited to the number of allowances (number of tons) held by the source. The allowance approach requires that the source emit no more SO_2 than they hold allowances for. In this system, excess allowances can be traded on an open market. In contrast, traditional, predefined emission limits apply to NO_x emissions.

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To verify compliance with the emission limitations, the acid rain program includes detailed CEMs requirements.⁶ In addition to verifying that the source emits no more SO₂ than the number of allowances they hold, or meet the applicable NO_x emission limits, additional monitoring is sometimes required. For example, heat input monitoring is required because NO_x emission limits are expressed in terms of heat input (e.g. 190 ng NO_x/J). Finally, continuous emission monitoring of opacity and carbon dioxide is mandated, however, CO₂ emission limits have not been promulgated.

Emission Limit Verification

Each monitoring system consists of several components, all of which must operate properly to satisfy quality assurance requirements. In addition to the monitoring equipment, all systems have a data acquisition and handling system (DAHS).

- SO₂ CEMS - SO₂ pollutant concentration, velocity, and diluent monitors.
- NO_x CEMS - NO_x pollutant concentration monitor, and CO₂ or oxygen (O₂) diluent monitor.
- Volumetric flow CEMS - flow monitor.
- CO₂ CEMS - CO₂ pollutant concentration monitor.
- Continuous opacity monitoring system (COMS) - opacity monitor.

The CO₂ diluent monitor used for the NO_x system can be used as the CO₂ pollutant concentration monitor for the CO₂ CEMS. As an alternative, CO₂ may be determined by measuring the carbon content of the input fuel.

In addition, the heat input must also be determined. Generally, the heat input is determined based on a fuel specific factor (F or F_g) and the volumetric flow through the stack.

Before a CEM system can be used to demonstrate compliance it must be certified by undergoing performance testing. Continued use is contingent on periodic quality assurance testing. The certification performance tests and quality assurance tests are similar to those required by NSPS, however, the specific performance specification testing procedures for sources subject to the acid rain requirements are contained in 40 CFR 75 Appendix A².

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404.1 ACID RAIN SOURCE CEM CERTIFICATION TESTS

For the most part, the certification tests for acid rain program CEMs are similar to those for NSPS sources (albeit with somewhat tighter limits, Table 400.3). However, several additional parameters must also be tested. A bias test must be applied to SO₂ pollutant concentration monitors, NO_x emission rate monitors, and flow rate monitors. A bias adjustment factor must be applied if the bias test shows a low bias. The error in linearity for an SO₂ or NO_x concentration monitor must not exceed or deviate from the reference value of the calibration gas by more than 5.0% or 5 ppm. For CO₂ or O₂ monitors, the linearity must not exceed 5.0% or 0.5 percent CO₂ or O₂. The response/cycle time for pollutant concentration or emission monitors must be less than 15 minutes.

Bias Test

Linearity

Response / Cycle Time

DAHS

The data acquisition and handling system (DAHS) also has a few additional requirements for acid rain sources. In addition to having the ability to read and record the data from the monitors, the DAHS must be able to provide PC format computer files (as an ASCII flat file) capable of transmission via diskette or other electronic media. The DAHS must be capable of interpreting and converting the signals from the SO₂ pollutant concentration, flow rate, and NO_x emission monitors to produce a continuous readout in units of the standard and reporting CO₂ mass emissions in tons. The DAHS must also be able to compute and record the monitor calibration error, bias adjustment factor, and all missing data (see Section 404.3).

Orientation

The flow rate monitor must also meet an orientation sensitivity test ($\leq 4.0\%$ deviation) and an interference check to preclude plugging and fouling.

404.1.1 Certification Test Dates and Schedules

Notification

Notification of an initial certification test must be given at least 45 days prior to the test. If, however, the test date must be changed, seven-day notice of the revised date is required.

If a monitoring system has lost its certification due to failure under section 40 CFR 75.20(a)(5) or has been substantially modified, recertification is required. Notification for the recertification test must be given at least seven days prior to the tests (two day notification of test date changes).

Upon completion of the certification procedures, the monitoring systems are deemed to be provisionally certified for use under the acid rain program for a

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period up to 120 days. Data measured and recorded during this period is considered valid quality assured data retroactive to the date and time of the test. The provisional certification is contingent on the test results showing that the monitors meet the certification requirements and that the provisional certification is not invalidated by a notice of disapproval within 120 days of receipt of the complete certification application.

Provisional Certification

A formal application for certification must be submitted within 45 days of completing the certification tests. The EPA has 120 days to approve or disapprove the application. If, after 120 days, no written notice is issued, the monitoring system is deemed certified. This is a difference from NSPS source CEMs, which do not have a certification application procedure. If the NSPS monitors pass their certification/specification tests they are deemed to be certified.

Certification Application

404.1.2 Certification Test Procedures

Appendix A of Part 75 contains the performance specifications and certification test procedures for monitoring systems required by the acid rain program. The specifications and procedures of Appendix A of Part 75 are similar to (and often refer back to) the NSPS performance specifications in Appendix B of Part 60. However, there are significant differences. Tests on acid rain program sources should follow Part 75, Appendix A. While 40 CFR 60, Appendix F requires the use of EPA protocol gases for quarterly audits, but not for daily checks, all daily calibrations and quarterly audits in the acid rain program must use protocol gases. The gases acceptable for the acid rain program include:

- Standard Reference Materials (SRM) - obtained from NIST
- NIST Traceable Reference Materials (NTRM) - obtained from a gas vendor, certified against an SRM
- EPA Protocol 1 Gases - vendor certified to be within $\pm 2.0\%$ of the concentration specified on the cylinder label
- Research Gas Mixtures - obtained from a gas vendor
- Zero Air Material - obtained from a gas vendor, certified to contain less than 0.1 ppm SO_2 or NO_x , less than 400 ppm CO_2 , and not to contain concentrations of other gases that will interfere with the SO_2 , NO_x , or CO_2 readings.

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Linearity Check

To check the linearity of each pollutant monitor and CO₂ or O₂ monitor certified, calibration gases are injected at three levels. The gases used are at 20 to 30 percent of span (low-level), 50 to 60 percent of span (mid-level), and 80 to 100 percent of span (high-level). The gas is introduced at the gas injection port, as close as possible to the inlet of the monitoring system. The calibration gas should pass through all filters, scrubbers, etc. used during monitoring. The monitor is challenged with each gas three times, but the same gas is not used twice in succession.

The results are recorded on a data form (example form in Appendix A of this manual). For each concentration use the average of the responses to determine the error in linearity:

$$LE = \frac{|R - A|}{R} \times 100$$

where LE = linearity error

R = reference value of the calibration gas

A = average monitoring system response

Linearity checks are acceptable if none of the test results exceed the applicable performance specification error of 5% of the reference method test value or 5 ppm for SO₂ or NO_x. For CO₂ and O₂ the linearity error limit is 5% of the reference method test value or 0.5 % CO₂ or O₂.

Calibration Error Test

The calibration error test tests the ability of the monitor to hold a calibration for an extended time. The test is conducted over the course of seven consecutive operating days (not necessarily seven consecutive days). The data points are taken once each day, approximately 24 hours apart.

Certified zero level (0 to 20 percent of span) and high level (80 to 100 percent of span) calibration gases are introduced into the gas injection port while the monitor is operating in its normal sampling mode. Manual or automatic adjustments should only be made after both the zero and high level checks have been made.

The readings of the monitor response should be recorded from the DAHS. The calibration error is calculated at each concentration each day:

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$$CE = \frac{|R - A|}{S} \times 100$$

where CE = calibration error

S = span of the instrument

The calibration error test is acceptable if the performance specification limits have been met.

The flow monitor calibration error test is conducted by introducing reference signals to the probe tip or to the transducer. The zero level signal should produce a 0 to 20 percent response and the high level signal should produce a response between 50 to 70 percent of the span. Calculate the results using the above equation.

Cycle Time / Response Time Test

The cycle and response time test is to test the rate at which the CEM system can respond to changes in stack gas. The test results are acceptable for monitoring system certification if none of the cycle times are greater than 15 minutes.

The test is conducted by injecting calibration gas and measuring the time required to respond. To determine the upscale cycle time, inject a zero level concentration calibration gas into the probe tip or injection port. When this has stabilized, record the stable starting gas value and start time from the DAHS. Next, allow the monitor to measure the concentration of stack flue gas emissions until the response stabilizes. Record the upscale elapsed time as the time required to reach 95% of the step change between stable starting zero gas value and the stable stack emissions value.

The downscale cycle time test is conducted similarly, starting with a high level calibration gas. Determine the downscale cycle time as the time required to reach 95% of the step change between the stable high level calibration gas concentration and the stable stack emissions value (Figure 404.1).

A stable value is equivalent to a reading with a change of less than 2% of the span value in two minutes, or a reading with a change of less than 6% from the measured average concentration in six minutes.

**95% Step
Change**

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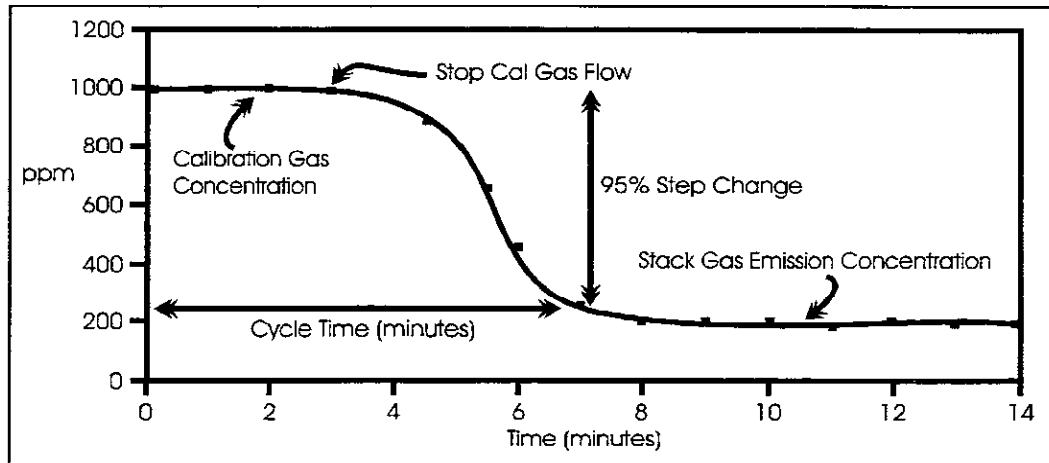


Figure 404.1 Downscale Cycle Time Test

The cycle time to be reported is the slowest elapsed time. For pollutant-diluent monitoring systems, report the longest cycle time of the component analyzers in the system. For time shared systems, the procedure must be done at all probe locations that will be polled within the same 15 minute period. To determine the cycle time, add together the longest cycle time obtained at each of the probe locations, including the time required for all purge cycles etc.

Relative Accuracy and Bias Tests

The relative accuracy certification tests are nearly identical to the RA tests for NSPS sources. The previously discussed RA testing (Section 401.1.3) can be followed for acid rain program sources if the needed added coordination between diluent and flow monitoring is also followed. The diluent (O_2 or CO_2), moisture, and flow measurements should be conducted simultaneously with the pollutant measurements when conducting RA tests. With the exception of the flow rate monitors, the relative accuracy procedures have been covered in Section 401.

The relative accuracy tests for the flow rate monitors are conducted at three different gas velocities or operating levels. The operating levels are selected by:

- Low-level - a frequently used low operating level within the range between the minimum safe operating level and 50% load
- High-level - a frequently used high operating level within the range between 80% load and the maximum operating level

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- Mid-level - the normal operating level or, if the normal operating level is within 10% of the low or high level, use a level that is evenly spaced between the low and high levels.

Calculate the flow monitor relative accuracy at each of the three operating levels. If a flow monitor fails the relative accuracy test on any of the levels, the entire test must be repeated after correcting the cause of the failure.

A portion of the relative accuracy test that is not included in the NSPS program tests is the Bias Adjustment Factor (BAF). A bias adjustment factor is required for acid rain program sources if the relative accuracy test shows that the monitors are reporting results with a low bias. Although not required, the bias adjustment factor can also be used in non-acid rain program source monitoring.

BAF

To conduct the bias test, calculate the difference between the pollutant concentration value obtained from the reference method and the value obtained from the pollutant monitor. The standard deviation and confidence coefficient are then calculated (Section 401.1.3). If the mean difference, \bar{d} , is greater than the confidence coefficient, the monitor has failed the bias test (for flow monitors, use the relative accuracy calculations for the flow rate closest to the normal operating level).

If the monitor fails the bias test, the values obtained from the DAHS need to be adjusted. The bias adjustment factor is calculated:

$$BAF = 1 + \frac{|\bar{d}|}{CEM}$$

where: BAF = bias adjustment factor calculated to the nearest thousandth

\bar{d} = arithmetic mean of the differences

CEM = mean of the data values reported by the monitoring system

The bias adjustment factor is then incorporated into the DAHS to correct the data reported:

$$CEM_i^{\text{adjusted}} = CEM_i^{\text{monitor}} \times BAF$$

where: CEM_i^{monitor} = unadjusted measurement provided by the monitor, at time i

CEM_i^{adjusted} = data value, adjusted for bias, at time i

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The bias adjustment factor should be applied to all monitor and monitoring system data from the date and time of the failed bias test until a relative accuracy test audit does not show bias. The bias adjustment factor should also be used in computing missing data substitutions and in reporting pollutant emission data.

Flow Monitor Interference Check

A flow monitor should be designed so that moisture does not interfere with the proper functioning of the monitoring system. Each monitor also should be designed with a means of detecting (on a daily basis) plugging of each sample line and sensing port. The flow monitoring systems should have a means of back purging to clear any accumulating deposits. On a quarterly basis the differential pressure systems must be checked for leaks.

Opacity Monitors

Opacity monitors installed as part of Acid Rain Program monitoring requirements are to be certified using the procedures and requirements in PS 1 of Part 60.

404.2 AUDIT TEST PROCEDURES

The monitoring systems installed under the acid rain program requirements must be on a daily, quarterly, semiannual, or annual basis to assess the quality assurance of the system (Tables 404.1 and 404.2).

404.2.1 Daily Assessments

Calibration error tests must be conducted approximately every 24 hours on all pollutant concentration, CO₂, O₂, and flow monitors. The calibration error test procedures are discussed above. Data from a monitoring system is considered prospectively quality assured for 26 hours (24 hours plus a two hour grace period) from the time of a successful calibration error test. Therefore, if a unit discontinues operation, or the use of a by-pass stack is discontinued, prior to the end of that time, the data for that operating day is considered valid. For units with add-on emission control and dual span or auto-ranging monitors and units that use the maximum expected concentration to determine the calibration gas values, the daily calibration error tests should be performed on those ranges that have been used since the last calibration error test.

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Table 404.1 Quality Assurance Audit Requirements

Test	QA Test Frequency Requirements		
	Daily	Quarterly	Semiannually
Calibration Error (2 point)	✓		
Interference (flow)	✓		
Leak (flow)		✓	
Linearity (3 point)		✓	
RATA (SO ₂ , NO _x , CO ₂) ¹			✓
RATA (flow, alternating 1 and 3 load) ²			✓

¹ Conduct annually if monitor meets accuracy requirements to qualify for less frequent testing

² Conduct 3-load RATAs annually if requirements to qualify for less frequent testing are met

Table 404.2 Relative Accuracy Test Frequency Incentive System

RATA	Semiannual	Annual
SO ₂	10% or 15 ppm if < 250 ppm; ±12.9 ng/J (0.03 lb/10 ⁶ BTU) for SO ₂ -diluent monitors ≤215 ng/J (0.5 lb/10 ⁶ BTU)	RA≤7.5% or ±8.0 ppm ¹
NO _x	10% or ±8.6 ng/J (0.02 lb/10 ⁶ BTU) if ≤86 ng/J (0.20 lb/10 ⁶ BTU)	RA≤7.5% or ±4.3 ng/J ¹
Flow (Prior to 1/1/2000) ²	15% or ±0.66 m/s (2 fps) if flow ≤3.28 m/s (10.0 fps)	RA≤10% or ±0.46 m/s ¹
Flow (After 1/1/2000) ²	10%	RA≤7.5% or ±0.46 m/s ¹
CO ₂ /O ₂	10% or mean difference between RM and CEM <1.0% CO ₂ or O ₂	RA≤7.5%

¹ The difference between the monitor and reference method mean values; low emitters or low flow only

² Conduct 3-load RATAs annually, if requirements to qualify for less frequent testing are met

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Interference Test

In addition to the calibration error test, a flow monitor must pass a daily interference test.

The EPA recommends that whenever the calibration error exceeds the limits for the applicable performance specification, the calibration of the monitor should be adjusted.

An out-of-control period occurs when the calibration error exceeds twice the performance specification value. This is 5.0% of span or 10 ppm (whichever is greater) for SO₂ and NO_x pollutant concentration monitors; 1.0% for CO₂ or O₂ monitors; and 6.0% of the span value for flow monitors. An out-of-control period also occurs whenever an interference is identified for a flow rate monitor. The out-of-control period begins with the hour of completion of the failed test and ends with the hour of completion of repair and recalibration or clearance of an interference and a successful interference test.

Data from a monitoring system are invalid if the monitoring system has not passed a calibration error or interference test within 26 hours of the last test or within eight hours of startup (assuming the monitoring system was in-control when the unit was shut down).

All daily calibration error and interference test data should be recorded and retained. Monitors that automatically adjust data to the corrected calibration values must be able to record either 1) the unadjusted concentration or flow rate measurement or 2) the magnitude of any adjustment factor.

404.2.2 Quarterly Assessments

Linearity Test

A linearity check must be conducted on each SO₂ and NO_x pollutant concentration monitor and each CO₂ or O₂ monitor at least once each quarter. The procedures for this test are discussed above (and in Appendix A of Part 75). The linearity tests should be conducted no less than two months apart.

Leak Check

A leak check must be conducted on differential pressure type flow monitors at least once each operating quarter. Again, the quarterly tests must be no less than two months apart. The leak check should include all sample lines and connections.

An out-of-control period occurs when the error in linearity at any of the three concentrations in the quarterly linearity check exceeds the applicable perfor-

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mance specification in Appendix A of Part 75. For the NO_x emission monitoring system, the system is considered out-of-control if either of the component analyzers fails its linearity check. The flow monitor is considered out-of-control if a leak is found in the system.

404.2.3 Semiannual and Annual Assessments

Relative accuracy test audits (RATA) must be conducted semiannually (no less than four months apart) unless the monitoring system qualifies for less frequent annual testing (Table 404.2). Table 404.2 indicates both semiannual and annual testing relative accuracy limits. Under the test frequency incentives contained in Part 75, a source meeting the more stringent annual limits may conduct relative accuracy test audits annually, otherwise semiannual RATA testing is required. For example, if a RATA on a NO_x emission monitoring system shows 5.7% error, then the next RATA on the NO_x monitoring system may be in a year's time. If the RATA had shown 8.4% error, the unit still would have passed the test, however, the next testing would have to be in six months. The procedures for the RATA testing were discussed in the certification testing section of this manual.

RATA

As was discussed previously, a bias test must be conducted along with a RATA. If the monitoring system fails the bias test, a bias adjustment factor must be applied. However, failure of the bias test does not result in the system or monitor being out-of-control. An out-of-control period occurs when the results of the RATA show an error greater than the limits for the semiannual testing requirements (Table 404.2, 40 CFR 75, and Appendix A).

404.3 MISSING DATA ESTIMATION PROCEDURES

When a monitoring system is out-of-control or inoperative, a certified backup or portable monitor should be used if available. The flue gases also could be routed to a stack with an operating certified monitor. If neither of these options are available, the missing data substitution procedures should be followed. There are four ways to calculate the values of the missing data: 1) Default missing data substitution procedures, 2) Standard missing data substitution procedures, 3) Parameter correlation missing data substitution procedures, and 4) Modified parameter missing data substitution procedures.

Out-Of-Control or Inoperative Periods

Default, Standard, Parametric, or Modified Procedure

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404.3.1 Default Data Substitution

Under this option the maximum potential concentration of SO₂ or the maximum potential NO_x emission rate (i.e. uncontrolled emission rate) is substituted for the missing data.

404.3.2 Standard Missing Data Substitution Procedure

This option allows the use of procedures that account for operation of the pollution control device. The control device must be operating properly and achieving removal efficiency equal to or greater than when the monitoring data is available. The standard missing data procedure is available after the first 720 hours of quality assured SO₂ data and after the first 2160 hours of quality assured NO_x emission rate and flow rate data have established the baseline conditions.

Tables 404.3 and 404.4 outline the degree of monitor data availability required and data averaging processes to estimate the data to substitute for the missing data. In general, higher emission level substitute data is required the longer the monitor outage lasts and the less reliable the CEM system has been.

Calculating the missing data also takes into account the load at which the unit operates. For NO_x and flow monitors the 2160 hour lookback period represents the average flow or emission rate over the past 2160 quality assured operating

Table 404.3 Missing Data Procedure for SO₂ CEMs

Trigger Conditions		Calculation Routines	
Availability	Duration (N) of outage (hours)	Method	Lookback Period
95% or more	N ≤ 24	Average	HB / HA*
	N ≥ 24	Maximum of average or 90th percentile	HB / HA* 720 operating hours
90% to 95%	N ≤ 8	Average	HB / HA*
	N ≥ 8	Maximum of average or 95th percentile	HB / HA* 720 operating hours
Below 90%	N > 0	Maximum value	720 operating hours

*HB / HA = the average of the SO₂ concentrations recorded the hour before and hour after the outage

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Table 404.4 Missing Data Procedure for NO_x and Flow CEMs

Trigger Conditions		Calculation Routines		
Availability	Hours (N) of outage	Method	Lookback Period	Load Ranges
95% or more	N ≤ 24	Average	2160 operating hrs	Yes
	N ≥ 24	Maximum of average or 90th percentile	HB / HA* 2160 operating hrs	No Yes
90% to 95%	N ≤ 8	Average	2160 operating hrs	Yes
	N ≥ 8	Maximum of average or 95th percentile	HB / HA* 2160 operating hrs	No Yes
Below 90%	N > 0	Maximum value	2160 operating hrs	Yes

*HB / HA = average of the hourly flow or NO_x emission data for the hour before and hour after the outage

hours at the corresponding unit load range recorded for each missing hour of monitoring data. Similarly, a lookback period of 720 hours is used for SO₂.

404.3.3 Parametric Correlation Data Substitution Procedures

For a unit with add-on SO₂ or NO_x emission controls and detailed parametric monitoring data, the missing data can be calculated using data based on the parametric monitoring. This procedure can only be used if the parametric monitoring plan and data calculation procedure has been approved by the EPA and the emission monitoring system has maintained at least 90% reliability. This procedure is detailed in 40 CFR 75 Appendix C.

404.3.4 Modified Missing Data Approach

A facility may petition the EPA to use a "more representative" value for the actual emissions, rather than the values substituted under the standard missing data procedure. To use this method, it must be demonstrated that the maximum values strongly overstate the actual emissions.

404.4 RECORDKEEPING AND REPORTING

Due to the amount of data to be handled in the acid rain program monitoring, CEM systems require a computerized system to record and report data. The computer system should be able to:

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**EER
DAR**

- Record output signals from one or more monitors
- Calculate, display, and store emission values
- Average stored emission rates as required by regulations and permit conditions
- Recognize excess emissions and notify operators
- Flag unusual operating conditions, such as startups, shutdowns, and malfunctions and record pertinent reasons
- Track the operation and calibration status of each monitor
- Control and monitor the status of CEM daily calibration sequences
- Store data for monthly and quarterly reports and automatically generate these reports
- Provide electronic communication capabilities with remote sites

There are two type of reports typically generated for the CEM systems: Excess Emission Reports and Data Assessment Reports. These reports are further discussed in Chapter 500.

Excess Emission Reports

- Front matter (cover, table of contents, certificate of accuracy)
- Report review checklists
- Review and sign-off by facility personnel
- Facility description
- CEM description
- Monthly emission summaries (in hourly increments)
- Monthly data recovery rate for CEM system

Data Assessment Reports

- Relative accuracy test audit (RATA) reports
- Relative accuracy audit (RAA) reports
- Cylinder gas audit (CGA) reports
- EPA performance audit results
- Daily calibration drift (in tabular and graphic forms)
- Corrective action reports

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405 REFERENCES

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11. McCoy, P.G., 1990, "The 'CEM Nation' an Analysis of U.S.EPA's Database - 1988", In: Proceedings - Specialty Conference on Continuous Emission Monitoring: Present and Future, Air and Waste Mgmt Assoc, Pittsburgh, PA, p 10-36.

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Continuous Emission Monitoring

Once emissions data has been recorded by the continuous emission monitoring system, it is important for reports to be submitted to the appropriate regulatory air agencies. Reports, both of emissions and CEM operation, are generally submitted quarterly. However, the schedule of submissions and specific information submitted varies by the monitoring program and reporting agency involved. Data from the CEM system must be retained and available for two¹ to three² years (depending on the program involved).

Quarterly Reports

There are four types of devices that can record and report CEM data: stripchart, data logger, dedicated personal computer, and facility mainframe computer. Increasingly, computerized recording and reporting is important. The acid rain program requires quarterly reports to be submitted in electronic media flat file format.²

Computerized Recording

A specific concern of computerized recording and reporting is the integrity of the data. The data should be saved to storage media (hard drive, etc.) at frequent intervals so any computer problems will result in minimal loss of data in active (RAM) memory. In addition, some degree of security should be provided to assure that the data, once recorded from the CEM system, cannot be modified. An agency auditor should examine the data security procedures as part of a systems audit.

Backups to archival storage (tapes, Zip® discs, etc.) should be conducted daily to assure that data cannot be lost to catastrophic computer failure. The backup should be stored in a secure location separate from the CEM computer area.

In many cases today CEM systems are required to have the ability to transmit data to the facility central offices or to the regulatory agency offices. In these cases, the telemetered data can be dialed up in real-time and the immediate emission status examined. One major precaution with these programs is that the on-line real-time data has not been quality assured.

On-Line Data

501 DATA AVERAGING

Regulatory reporting requirements usually specify the minimum number of CEM data points and averaging time required in the reported emission data point. Monitoring systems commonly poll the analyzer data in 10 second averages. A number of these analyzer data segments are then averaged into the required reporting average. For example, for gas analyzers, the 10 second data is averaged into 15 minute averages,² which are usually further averaged into hourly

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Rolling
Averages

averages. The averaging requirements further complicate the CEM recording and reporting procedures, but provide for a consistent reporting format. In many cases, the requirements will necessitate that the averages be determined by computerized data acquisition systems.

Block averages and rolling averages are two averages that are commonly used in CEM reporting. A rolling average is an integration of data over a specified time period with an overlap between neighboring averages (Figure 501.1a). In a three hour rolling average, the average of the first three hourly data sets gives the first average. After four hours the three hour rolling average consists of the average of the second through fourth hourly averages, the first having been removed from averaging. The next period will be an average of hours three through five, etc. Each successive average adds the next hour and removes the oldest hour.

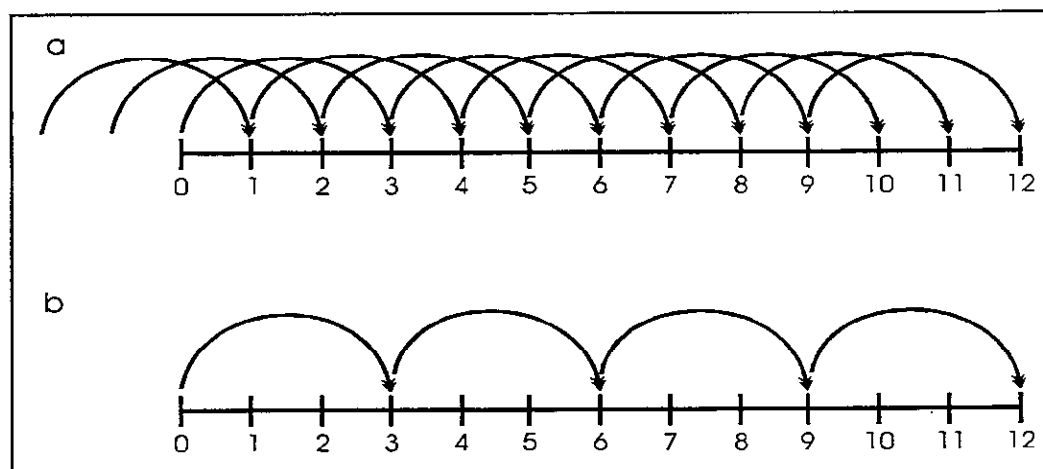


Figure 501.1 Construction of Three Hour Averages; a) Rolling Averages, b) Block Averages

Block
Averages

Block averages are somewhat simpler. Each successive average is distinct from the previous one (Figure 501.1b). The first three hour block average consists of the average of the first three hourly average data sets. The next three hour block average consists of the average of hours four through six, then seven through nine, etc.

Rolling averages provide a means of smoothing data without resorting to excessively long averaging periods. A rolling average also maintains more data points while still providing the averaging desired. A set of 24 hourly data points can give 22 three hour rolling averages or eight block averages.

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The longer the rolling averaging period, the easier it is for a facility to meet the emission standard³.

501.1 OPACITY MONITOR AVERAGES

Except during periods when monitoring systems (including opacity, gaseous, flow, parametric, etc. monitors) are offline for required maintenance, calibration checks, and zero and span adjustments, the monitoring system must be in continuous operation. Opacity monitors must complete a minimum of one cycle of sampling and analyzing emission levels every ten seconds. Data recording must be in six minute averages consisting of 36 or more data points equally spaced over each six minute period.

Six Minute Averages

501.2 GASEOUS MONITORING SYSTEM AVERAGES

The minimum cycle of operation (sampling, analyzing, and data recording) for a CEM other than opacity, is once every 15 minutes. An hourly average of the data may be calculated as the average of four or more data points equally spaced over each one hour period (i.e. at least one data point in each 15 minute quadrant of an hour.) The minimum data required to calculate an hour average is two data points. These data points must be separated by at least 15 minutes under the Acid Rain Program.

Hourly Averages

All data must be included in the hourly average. If the cycle time is more frequent than once every 15 minutes, more than four data points will be used in the hourly average.

502 EMISSION DATA REPORTS

Periodic reports of emissions indicated by the CEM systems are generally required of sources required to operate monitoring systems. Depending on the program and agency, a source may be required to report periods of exceedences of emission standards, operational status of the CEM systems, quality assurance status of the CEM system, and/or complete records of emissions or unit operating parameters from the monitored unit.

Excess Emission Reports

One of the most common reporting formats is the excess emission report (EER). This format originated with NSPS CEMs and has also been frequently used for state and local program reporting. The EER contains reports on:

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- The magnitude of any excess emissions (generally in units of the standard)
- The dates and times of the excess emissions
- The reasons for the excess emissions
- The corrective actions taken to end the excess emission event and prevent its recurrence

The data requirements of an EER can be very extensive. The list of exceedence times and values for a unit with frequent exceedences can become quite long, especially for opacity exceedences.

It should be noted that CEM systems used for direct determination of compliance or Part 75 sources must submit all data regardless of emission exceedances.

502.1 CALIFORNIA AND DISTRICT REPORTING REQUIREMENTS

H&SC 42706

The California Health and Safety Code⁴ (H&SC) requires that exceedences of the emission standards be reported to the district within 96 hours. The district, in turn, is required to report the exceedence to the state board within five working days (H&SC 42706). The CARB does not require direct routine reporting of CEM data or operation since the primary responsibility for stationary sources rests with the local and regional authorities.

The reports of violations submitted to CARB by the districts should include:

- Date of the violation
- Source name and location
- Emission point
- Pollutant monitored
- Rule violated
- Emission limit
- Level of excess emissions
- Cause of the exceedence
- Time period of excess emissions
- District action taken or planned

A suggested reporting form for H&SC 42706 reporting is shown in Figure 502.1 (also a blank form in Appendix A).

Continuous Emission Monitoring - Excess Emission Report

To: Air Resources Board
Compliance Division
Attn: Verna Ruiz
FAX: (916) 445-5745

From: _____

The following excess emission report* is submitted as required by Health and Safety Code Section 42706:

Date / Time Period	Facility / Location	Permit Unit	Pollutant	Rule	Limit	Cause	APCD Action Taken or Planned

* The District may submit its own excess emission report form in lieu of this one.

Figure 502.1 Example CARB Excess Emission Report Form

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Monitoring**

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District Programs

Each district in California has developed and adopted its own monitoring programs and requirements, although many have incorporated the federal monitoring programs into their regulations by reference.

In addition to the reporting of excess emissions, most district programs require quarterly or monthly reporting. For example, the South Coast Air Quality Management District⁵ requires a monthly summary of the concentration and emission data from the CEM system. The summaries may also require additional information to evaluate the accuracy and precision of the measurements.

The SCAQMD also has an emission marketing program (RECLAIM) which requires emission monitoring. Sources in the RECLAIM program are required to electronically report the SO_x and NO_x mass emissions daily and a monthly summary of the SO_x and NO_x emissions.

502.2 NSPS DATA REPORTING

Under the NSPS regulations (40 CFR 60.7) anyone required to install and operate a CEM system is required to submit an excess emissions and monitoring systems performance report and/or a summary report. The minimum reporting would be semiannually. However, an NSPS subpart, or reporting agency, may require more frequent reporting. Also, if the data is used for direct determination of compliance, quarterly reporting is required.

Summary Report

A summary report (Figure 502.2) contains a summarization of the monitor's operation during the reporting period. In addition to the information in Figure 502.2, the summary report should contain a second page describing any changes since the previous report and a certification signature. An example form is contained in Appendix A of this manual. A separate summary report should be submitted for each pollutant monitored at each facility.

If the total duration of excess emissions for the reporting period is less than 1% of the total operating time, and the total CEM system downtime, including calibrations, is less than 5% of the total operating time, only the summary report is required by NSPS regulations. However, if either the excess emission time exceeds 1% or the downtime exceeds 5%, an excess emission report is required in addition to the summary report.

EER

The written reports of excess emissions must include the following and be submitted by the 30th day following the end of the calendar quarter (or half-year):

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Monitoring

CEM Summary Report

Company	Date ____ / ____ / ____
Address	
Analyzer Manufacturer	Model/Serial Number
Location	

Reporting Period Dates: From ____ / ____ / ____ to ____ / ____ / ____	
Pollutant (circle one) SO ₂ / NO _x / TRS / H ₂ S / CO / Opacity	
Emission Limitation:	
Date of Latest Certification or Audit: ____ / ____ / ____	
Process Unit(s) Description:	
Total Source Operating Time in Reporting Period: _____ Hours	

Emission Data Summary:

Duration of Excess Emissions in Reporting Period Due To:	
Startup / Shutdown	_____ Hours (Minutes)*
Control Equipment Problems	_____ Hours (Minutes)*
Other Known Causes	_____ Hours (Minutes)*
Unknown Causes	_____ Hours (Minutes)*
Total Duration of Excess Emissions	_____ Hours (Minutes)*
Percent Time Excess Emissions	_____ Hours (Minutes)* **
(Total Duration of Excess Emissions / Total Source Operating Time x 100)	

Monitor System Performance Summary

Monitoring System Downtime in Reporting Period Due To:	
Monitor Equipment Malfunction	_____ Hours (Minutes)*
Non-Monitor Equipment Malfunction	_____ Hours (Minutes)*
Quality Assurance Calibration	_____ Hours (Minutes)*
Other Known Causes	_____ Hours (Minutes)*
Unknown Causes	_____ Hours (Minutes)*
Total Monitoring System Downtime	_____ Hours (Minutes)*
Percent Monitoring System Downtime	_____ Hours (Minutes)* **
(Total Duration of Downtime / Total Source Operating Time x 100)	

* For opacity record in minutes; for gases record in hours

** If total duration of excess emissions is greater than 1% or total downtime greater than 5%, submit both Summary Report and Excess Emission Report

Figure 502.2 Example Summary Report Form

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- Magnitude of excess emissions, any conversion factors used, and the date and time of commencement and completion of each occurrence of excess emissions.
- Specific identification of any time of excess emissions that occurs during startups, shutdowns, and malfunctions. The nature of any malfunction must be reported along with the corrective action or preventative measures taken.
- The date and time identifying each period in which the CEM system was inoperative (except for zero and span checks). The nature of the system repairs and adjustments must be reported.
- If no excess emissions occur in the reporting period or the monitor has not been inoperative or needed repairs and adjustments, such a negative declaration should be made in the report.

502.3 ACID RAIN PROGRAM DATA REPORTING

**P.C. Format
Electronic
Flat File**

The Acid Rain program (Part 75) requires that the CEM data and operational reports be submitted quarterly and in flat file electronic format capable of being read by computer (PC platform). The electronic reports must be submitted within 30 days of the end of the calendar quarter. Unlike the NSPS monitoring programs and many state and locally required CEM programs, all data must be submitted for monitors required by the Acid Rain Program.

The Acid Rain Program requires extensive data reporting. Figure 502.3 outlines the general recordkeeping requirements and Figure 502.4 outlines the general certification, quality assurance, and quality control recordkeeping requirements. There are additional requirements for specific situations, alternate procedures, and exceptions in Subpart F of 40 CFR 75 (40 CFR 75.50 - 56) which have not been included in the figure outlines. The data recorded outlined in Figures 502.3 and 502.4 for general recordkeeping, in addition to the data recorded for specific situations, alternate procedures, and exceptions must all be reported except:

- Descriptions of adjustments, corrective actions, and maintenance items;
- Information which is incompatible with electronic reporting (e.g. field data sheets, laboratory analyses, quality control plan, etc.);

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Continuous
Emission
Monitoring

General Recordkeeping Provisions

Operating parameter provisions

- Date and hour
- Unit operating time
- Hourly gross load
- Load range
- total heat input

SO₂ emission record provisions

SO₂ monitor data

- Component/system identification code
- Date and hour
- Hourly average SO₂
- Hourly average SO₂ adjusted for bias
- Percent monitor data availability
- Code for method of determination of hourly average SO₂

Flow monitor data

- Component/system identification code
- Date and hour
- Hourly average volumetric flow
- Hourly average volumetric flow corrected for bias
- Hourly average moisture content (if dry SO₂ monitor)
- Percent monitor data availability
- Code for method of determination of hourly average flow

SO₂ mass emissions

- Date and hour
- Hourly average SO₂ mass emissions
- Hourly average SO₂ emissions corrected for bias
- Code for emissions calculation formula

NO_x emission record provisions

- Component/system identification code
- Date and hour
- Hourly average NO_x concentration
- Hourly average diluent concentration (percent O₂ or CO₂)
- Hourly average NO_x emission rate
- Hourly average NO_x emission rate corrected for bias
- Percent monitoring system data availability

Figure 502.3 Part 75 General Recordkeeping Provisions

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Code for method of determination of hourly average NO _x
Code for emissions calculation formula
<u>CO₂ emission record provisions</u>
Component/system identification code
Date and hour
Hourly average CO ₂ concentration
Hourly average volumetric flow
Hourly CO ₂ mass emissions
Percent monitor data availability
Code for method of determination of hourly CO ₂ mass emissions
Code for emissions calculation formula
<u>Alternative CO₂ emissions record provisions</u>
Date
Daily combustion formed CO ₂ mass emissions
Flag to indicate the use of optional procedure to adjust combustion formed CO ₂ mass emissions for carbon retained in flyash (coal fired units only)
Adjustment factor (if above procedure used)
Daily sorbent related CO ₂ mass emissions for units with desulfurization systems that generate CO ₂
Daily total CO ₂ mass emissions for units with desulfurization systems that generate CO ₂
<u>Opacity Records</u>
Component/system identification code
Date, hour, and minute
Six minute average opacity
Code indicating exceedance of applicable opacity standard
Percent monitor data availability

Figure 502.3 (cont.) Part 75 General Recordkeeping Provisions

- Opacity data records; and
- Details of missing data substitutions for units with add-on SO₂ or NO_x emission controls that do not elect to use the approved site-specific parametric monitoring procedures for calculation of substitute data.

The report should also include:

- Tons of SO₂ emitted during the quarter and cumulatively for the calendar year;

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Continuous
Emission
Monitoring

Certification, Quality Assurance, and Quality Control Record Provisions

Daily and seven day calibration error tests (SO₂ or NO_x pollutant concentration, flow, CO₂, diluent gas monitors)

Component/system identification code

Instrument span

Date and hour

Reference value

Observed value

Percent calibration error

Calibration gas certification (for seven day calibration error tests)

Description of adjustments, corrective actions, or maintenance following test

Daily interference checks (flow monitors)

Code indicating pass/fail

Description of adjustments, corrective actions, or maintenance following test

Initial and subsequent linearity checks (SO₂ or NO_x pollutant concentration, CO₂, diluent gas monitors)

Component/system identification code

Instrument span

Date and hour

Reference value

Observed value

Percent error at each of three reference gas concentrations

Description of adjustments, corrective actions, or maintenance following test

Quarterly leak checks (flow monitors)

Code indicating pass/fail

Description of adjustments, corrective actions, or maintenance following test

Initial and subsequent relative accuracy tests and test audits (SO₂ or NO_x pollutant concentration, flow, CO₂ pollutant concentration monitors, NO_x emissions monitoring system, SO₂-diluent emission monitoring system, approved alternative monitoring system)

Date and hour

Reference method(s) used

Figure 502.4 Part 75 Certification, Quality Assurance, and Quality Control Recordkeeping Provisions

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Individual test run data

Date, hour, and minute of beginning of test run

Date, hour, and minute of end of test run

Component/system identification code

Run number

Run data for each monitor

Run data for reference method

Flag value (0 or 1) indication data used in relative accuracy and bias calculations

Calculations and tabulated results

Mean monitoring system measurement values

Mean reference method values

Mean differences

Standard deviation

Confidence coefficient

Relative accuracy test results (record each result and load level for three level flow monitor tests)

Bias test results

Bias Adjustment Factor (1.0 if passed test)

Description of adjustments, corrective actions, and maintenance following test

F-factor value(s) used to convert NO_x pollutant concentration and diluent gas (O₂ or CO₂) concentration measurements into NO_x emission rates, heat input, or CO₂ emissions

Cycle time test (SO₂, NO_x, CO₂, or O₂ pollutant concentration monitor, NO_x - or SO₂-diluent emission monitoring system)

Component/system identification code

Date

Start and end times

Upscale and downscale cycle times for each component

Stable start monitor value

Stable end monitor value

Reference value of calibration gas(es)

Calibration gas level

Cycle time result for the entire system

Results of all trial runs, certification tests, QA activities, and measurements necessary to substantiate compliance

Figure 502.4 (cont.) Part 75 Certification, Quality Assurance, and Quality Control Recordkeeping Provisions

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- Average NO_x emission rate during the quarter and cumulatively for the calendar year;
- Tons of CO₂ emitted during the quarter and cumulatively for the calendar year;
- Total heat input for the quarter and cumulatively for the calendar year; and
- Information to document the measured SO₂ removal for units using qualifying Phase I emission reduction technology. This information should include all measurements and calculations necessary to substantiate that the technology achieves the overall percentage reduction in SO₂ emissions required.

A paper compliance certification must accompany the electronic data submission. This compliance certification must state:

Compliance Certification

- Whether the data submitted were recorded in accordance with applicable requirements;
- Description of the measures taken to cure the causes for the missing data periods;
- Certification that during periods when data was substituted add-on emission controls were operated within the range of parameters listed in the monitoring plan; and
- Certification that substitute values recorded during the quarter do not systematically underestimate the SO₂ or NO_x emissions.

Excess opacity emissions, as outlined in Figure 502.3, should be reported to the applicable state or local air pollution control agency in a manner and format specified by that agency.

Excess Emissions Reporting

502.4 EXCESS EMISSION REPORT REVIEW

When an Excess Emission Report is received by the district or state air control agency, it should be reviewed for completeness and indicated violations.⁶ A review form (example form in Appendix A of this manual) greatly facilitates the review process and is helpful in determining the existence of violations and their severity. A standardized review form also assures that all sources are treated equally.

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The example review form has fields to fill in information about the timeliness and completeness of the submission as well as detailed information about the emissions and operation of each monitor and parameter. The final page of the form has space for recommended follow-up activities needed to obtain additional information if something was left out of the EER. It also has fields for the reviewer to use to recommend enforcement action, if necessary.

503 ENFORCEMENT USING CEMS

**Continuous
Compliance
Follow-Up
Inspections
Violation
Catagories**

Continuous emission monitors are a key element of a stationary source compliance strategy for evaluating compliance on a continuous basis.⁶ In addition to emissions compliance, the CEM data is useful for identifying sources for more in-depth follow-up inspections. There are five principal categories of continuous emission monitoring related violations: 1) emission violations, 2) percentage reduction violations, 3) data capture violations, 4) operation and maintenance violations, and 5) procedural and reporting violations.

503.1 EMISSION VIOLATIONS

**Direct
Compliance
Compliance
Indicating**

An emission violation occurs whenever a pollutant emission rate, averaged over the appropriate time interval, is legally documented to exceed its emission standard. The data from a direct compliance CEMs monitor is sufficient to issue the Notice of Violation (NOV). If the CEM is considered compliance indicating only, the data from the CEM is considered indicative of emission violations. The legal documentation required for a Notice of Violation from a compliance indicating system usually requires corroboration data from the official compliance test method.

The California Health and Safety Code (Section 42706) requires that any excess emissions indicated by the monitoring system be reported to the district within 96 hours. The district then must report the violation to the state board within five working days.

EER

Most agencies require reports of emission data and CEM operation by sources to be submitted quarterly (some districts require more frequent reporting). These excess emission reports (EERs) must indicate the time, duration, etc. of all periods of excess emissions and include data showing compliance before and

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Continuous Emission Monitoring

after the excess emission or monitor out-of-service period. Certain excess emissions may be allowed (startup, etc.), but must be reported. If non-compliant excess emissions occur, the EER may be used in enforcement actions, even when the CEM reports compliance indicating data, since the CEM data can provide a part of the record in the enforcement proceedings. Section 113 of the US Clean Air Act⁷ states:

"Whenever, on the basis of any information available to him, the Administrator finds that any person is in violation of any standard of performance...he may bring civil action in accordance with subsection 113(b)."

Every quarter (or more frequently if required by the air control agency) a source must submit an operational summary for each CEM. For Acid Rain Program monitors, a complete data set of the quarterly monitor readings must also be submitted along with the summary. NSPS sources require the EER be submitted only if excess emissions occurred more than one percent of the source operating time in the quarter, or the monitor was off line five percent or more of the source operating time (or both conditions). A state or locally mandated monitor may have additional requirements.

Determination of source compliance can be made on a number of levels when using the EER approach.⁶

Level 1

On the first level, the agency evaluates the source's quarterly EERs, checking on the following items:³

- Reports of periods and magnitudes of excess emissions;
- Nature and cause of each period of excess emissions and documentation of compliance before and after the excess emission period;
- Periods during which the continuous monitoring system was inoperative;
- Records of calibration checks, adjustments, and maintenance performed on the monitoring system.

Records Review

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Table 503.1 EPA Region IV EER Target Criteria and Follow-Up

Percentage of Time Out of Compliance	Percentage of Monitor Downtime	Appropriate Follow-Up Action
<2.0%	<2.0%	Send letter acknowledging receipt of EER and encouraging proper O&M of CEM and facility.
>2.0 and <5.0%	>2.0 and <5.0%	If either or both cases exist, then warn by letter or telephone call of unacceptable condition.
>5.0 and <10.0%	>5.0 and <10.0%	If either or both cases exist, then warn by letter of unacceptable condition, request explanation of condition, and request corrective action plan to prevent condition from reoccurring.
>5.0 and <10.0% for two consecutive quarters or >10.0%	>5.0 and <10.0% for two consecutive quarters or >10.0%	If either or both cases exist, then issue NOV and require performance (compliance) test for monitored pollutant, monitor certification (PS) tests, and request corrective action plan to prevent condition from reoccurring.

The review of the EERs should reveal source operation or control equipment problems. The agency then can evaluate the severity of the problem. Often a telephone call to the source can clarify the nature of the problem area. This may indicate that further action is called for or avoid more extensive agency action for a simple, solved problem.

EER Follow-Up

The EERs can be used to initiate several levels of enforcement activity (Table 503.1). For example, if a monitor was operating well, but reported excess emissions occurring for a total of 130 hours during the quarter (6% of the time) and 150 hours (7%) the next, according to the guidelines in Table 503.1 a Notice of Violation should be sent to the facility, performance tests conducted, and a corrective action plan prepared. After the first quarter (with 130 hours of excess emissions) the source would have been warned and a corrective action plan requested; after the second quarter of excess emissions significant corrective and enforcement actions would be warranted.

Table 503.1 is a table of follow-up actions devised by EPA Region IV. This is an example enforcement guideline, other regions, states, or districts may devise other follow-up criteria. An inspector should follow his or her agency's criteria. However, written follow-up criteria should exist to assure that follow-up occurs and that all sources are treated alike.

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Continuous Emission Monitoring

Level 2

If the EER shows operational problems at the plant, a level 2 inspection may be specified. A level 2 inspection is basically a systems audit in which the facility, control equipment, and the CEM system undergo review (see Section 402.1).

System Audit

Level 3

Based on the results of the level 2 inspection, or information from the EER showing accuracy and precision problems, a level 3 inspection may be conducted. The level 3 inspection consists of limited testing of the CEM by conducting performance audits, in which the CEM is challenged with certified gases and/or filters to check the data validity.

Performance Audit

Level 4

If--after review of the EER, inspections, and an audit--there are still doubts or suspicions about the data quality or an indicated emission violation, a comprehensive compliance test may be ordered. At this level a complete source test may be conducted using reference method or performance specification test method tests. If the CEM cannot be used for direct compliance determinations, a level 4 test is required before legal action can be initiated for emission violations (although other violations may be pursued without this test).

Source Test

Performance Specification Test

503.2 PERCENTAGE REDUCTION VIOLATIONS

A percentage reduction violation occurs when the control device fails to achieve the required efficiency of pollutant concentration reduction in the flue gas. Many regulations or permits that call for scrubbers, baghouses, etc. specify that a certain percentage reduction in pollutant concentration must be achieved by the device. If that reduction is not achieved, issuing a Notice of Violation should be considered.

Control Device Failure

Subparts Da, Db, Dc, Ea, and J of NSPS¹ have such emission reduction requirements. In Subpart Da the emission limit is also tied to the degree of pollutant reduction. For solid fuels, if 90% or better reduction of SO₂ concentrations is maintained, the emission limit is 520 ng/J; however, with only 70% reduction the emission limit is 260 ng/J. Another program calling for emission reductions, the Acid Rain Program Qualified Phase I Technology provisions, calls for 90% control of SO₂.

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Monitoring System Failure

503.3 DATA CAPTURE VIOLATIONS

A data capture violation occurs if the monitoring system fails to record valid data for the minimum number of data points, hours, days, or percentage of time. Data capture rate requirements may be written into any permit that contains monitoring requirements. They also may be regulatory provisions.

Excessive monitor downtime should be noted by the air agency and appropriate follow-up conducted. Table 503.1 outlines specific follow-up procedures from the EPA region IV enforcement policies. Other EPA regions, states, or districts may have somewhat different guidelines; however, it is important to have a follow-up policy. Poor monitor data capture and frequent downtime can result in significant enforcement actions taken against the source.

For example, using the Region IV table, an EER may indicate that a source has had very few emissions in excess of the limit; however, the monitoring system was off line for 259 of the 2160 operating hours in the quarter. Since the monitor downtime (12%) was in excess of the target performance criteria, the Region IV Guidelines indicate that a Notice of Violation should be issued, testing conducted, and a corrective action plan prepared.

Several direct compliance CEMs in the NSPS Subparts (Da, Db, Dc, Ea, and J) contain data capture requirements. These data capture rates may be stated in several ways. Subpart Da requires that at least two valid data points make up an hourly average, at least 22 valid hours of data make up a valid day of data, and at least 22 out of 30 successive operating days must be valid data days. In Subpart Ea a data capture rate of 75% of operating hours per day (at least two valid data points used to calculate a data hour) and 75% if the days per month must be maintained. For Subpart J three hour rolling averages of SO₂ must be made up of three contiguous valid data hours. If these requirements are not met, the Region IV guidelines indicate that a Notice of Violation should be issued and corrective action required.

An additional aspect of the data capture rate extends to when an EER must be filed for an NSPS source requiring a CEM. If the total duration of excess emissions is less than 1% of the total operating time, and the monitoring system down- time is less than 5% of the total operating time, only the CEM summary report needs to be filed; the EER is not required. If either the excess emission time or the downtime exceed 1% or 5%, respectively, the EER must be filed in addition to the summary report.

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Continuous Emission Monitoring

The Acid Rain Program requires that missing data be filled in.² If the certified primary monitoring system is down, data from a certified redundant or backup monitor can be substituted. If data from a redundant or backup monitor are used, it can be reported as quality assured data and used to calculate monitor data availability. If no quality assured data is available for an operating period, missing data procedures in 40 CFR 75 Subpart D must be used to estimate emissions for that downtime.

Since all emissions must be accounted for in the Acid Rain Program, the missing data routines are important. Initially, an average of quality assured data before and after the downtime or the maximum potential to emit are used to calculate the missing data.

After the initial operating period, the standard missing data procedures are used. The standard missing data routines take into account the monitor data availability and the length of the downtime when estimating the missing data. The longer the downtime and the lower the quality assured monitor data availability the greater the substituted missing data estimates could potentially be. An improved data capture rate may result in less missing data estimate requirements.

503.4 OPERATION AND MAINTENANCE VIOLATIONS

The term "operation and maintenance violation", as it pertains to CEMs, refers to a regulatory or permit "good operating and maintenance practice" provision. An example is 40 CFR 60.11(d)¹ which states:

"At all times, including periods of startup, shutdown, and malfunction, owners and operators shall, to the extent practicable, maintain and operate any affected facility including associated air pollution control equipment in a manner consistent with good air pollution control practice for minimizing emissions."

Section 60.11(d) goes on to allow any available information, including CEM data, to be used to determine whether proper operation and maintenance (O&M) practices are being followed. Good O&M provisions are also included in NESHAP monitoring requirements (40 CFR 61.12(c)). State implementation plans also often incorporate regulatory O&M practices provisions.

Missing Data

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In addition, permits frequently contain O&M provisions. From a regulator's standpoint, an O&M permit provision can be a useful enforcement provision when a facility is poorly operated and generating unreliable emission data.

Table 503.2 EPA SO₂ Continuous Compliance Strategy (LT = Length of Time)

Description of Violation	Decision Point
<u>Stack Test Data</u>	
Emission limit exceeded	Proceed with enforcement
<u>CEMs and/or FSA is the Emission Compliance Method</u>	
Emission Limit Exceeded Formula: (LT in violation/LT of operation) x 100%	1 percent
Emission Reduction Shortfall (percent of time not meeting emission reduction requirement) Formula: (LT in violation/LT of operation) x 100%	1 percent
Data Acquisition Shortfall for long averaging times Formula: (LT of data inadequacy/LT of operation) x 100%	1 percent
Data Acquisition Shortfall for short averaging times Formula: (LT of data inadequacy/LT of operation) x 100%	5 percent
<u>CEMs and/or FSA is not Emission Compliance Method</u>	
Emission Limit Exceeded Formula: (LT in violation/LT of operation) x 100%	5 percent
Emission Reduction Shortfall (percent of time not meeting emission reduction requirement) Formula: (LT in violation/LT of operation) x 100%	5 percent
Data Acquisition Shortfall for long averaging times Formula: (LT of data inadequacy/LT of operation) x 100%	5 percent
Data Acquisition Shortfall for short averaging times Formula: (LT of data inadequacy/LT of operation) x 100%	5 percent

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Continuous Emission Monitoring

503.5 PROCEDURAL AND REPORTING VIOLATIONS

Procedural and reporting violations encompass a wide variety of violations associated with the installation, certification, calibration, maintenance, recordkeeping, and reporting of a CEM system. This category of violations largely consists of "paperwork" violations relative to CEM system implementation. Many pages of regulations falling into this category exist for every program requiring CEMs. A violation occurs whenever a source owner or operator fails to implement any CEM program element of a regulation, permit, order, etc.

Although these violations are not directly for emissions, they are important to all aspects of a CEM program as well as district-wide general air pollution program operation. The procedural and reporting provisions assure that monitoring systems are properly implemented and that reliable emission data are available to the agency and public.

Implementation and Documentation Violations

Data Reliability

503.6 COMPLIANCE STRATEGY

An air control agency should devise a continuous compliance assurance strategy which would use the data reported by the source (and any other data available) to determine the appropriate enforcement procedures. A defined strategy will help assure that all sources regulated by the agency are treated equally. An example compliance strategy from the EPA⁸ for determining enforcement of SO₂ continuous compliance utilizes the CEM and fuel sampling and analysis (FSA) reports submitted and a calculated noncompliance percentage (Table 503.2). The calculated percentage is compared with an action guideline value and the designated follow-up actions pursued. If the percent is less than the action guideline value, additional information is recommended before proceeding with enforcement actions. If the percent is greater than or equal to the guideline value the designated enforcement action should be pursued.

Data acquisition shortfalls reflect the percentage of data not meeting the standards set by the applicable rule. If the data rule requires monitor availability 22 of 30 days, then the data acquisition shortfall is the difference between 22 days and the actual (lesser) number of days of valid data provided.

An example use of Table 503.2 would be if a large NSPS Subpart Da coal fired powerplant achieved 83% reduction of SO₂ (vs required 90%) for a 24 hour period (based on a 30 day rolling average). The noncompliance percentage for

Action Guidelines

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this quarter would be 1.1% [24hrs/(90days x 24 hrs/day)], indicating that enforcement should be pursued. If the calculation would have fallen below 1%, but the report indicated that the source was not continuously achieving 90% SO₂ emission reduction, additional information should be requested. Depending on that additional information, enforcement could still be pursued.

503.7 INSPECTIONS

H&SC 42707

An important part of using CEMs to assure compliance with emission limits is periodic inspections⁹. Inspections will assure the regulator that the source is operating in compliance and will provide an incentive for the source to maintain proper operation and recordkeeping of the CEM. Section 42707 of the California Health and Safety Code⁴ states that "(t)he air pollution control officer shall inspect, as he determines necessary, the monitoring devices installed in every stationary source of air contaminants located within his jurisdiction required to have such devices to insure that such devices are functioning properly." Since quarterly audits are required of most CEMs, at least some degree of quarterly review is required. At least annually, the operator of each CEM must conduct a parallel source testing audit (Relative Accuracy Test Audit) which should be witnessed by an inspector.

In addition to examining the CEM as operating during the inspection, the inspector should include an examination of data generated since the previous inspection and logbook entries. Routine preventive maintenance should be performed on a defined schedule and recorded in maintenance and instrument logbooks. An inspector should examine the maintenance log during the CEM inspection. Entries in the logs should correspond to the written maintenance and QA plans. The maintenance log should also document any emergency maintenance and reflect upset periods reported according to upset and breakdown regulations.

The California Health and Safety Code (Section 42706) requires excess emissions to be reported to the district within 96 hours and the district to report the violation to the state board within five working days. This includes any maintenance that may have resulted in excess emissions.

Three common types of inspections are: the equipment inspection, the data and records inspection, and the audit. All three inspection types are often conducted simultaneously. In addition to examining the condition and configuration of the equipment and the CEM records, the inspector should observe a daily calibration cycle.

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Continuous Emission Monitoring

503.7.1 Equipment Inspections

Equipment inspections serve as a periodic check of the CEM system condition, configuration, and maintenance. The two main considerations are: is the system in operable condition and does the system configuration match that of the previous inspection and required by the permit or regulation? Included in Appendix A of this manual is a form (CEM Analysis System Inspection) that can be used to record information during equipment inspections. Good references for the inspector to have are: *Performance Audit Procedures For Opacity Monitors* (EPA-450/4-92-010)¹⁰, *Inspection Guide For Opacity Continuous Emission Monitoring Systems* (EPA-340/1-88-002)¹¹, and *Field Inspector's Audit Techniques: Gas CEMS's Which Accept Calibration Gases* (EPA-340/1-89-003)¹² from the U.S.EPA

There are five general CEM subsystems of equipment checks:

- Probe and umbilical line
- Conditioning and dilution air system
- Analyzers
- Accessories (i.e. gas cylinders, regulators, etc.)
- Data acquisition and handling systems (DAHS)

The inspector should observe the status and operation of each of these subsystems, however, the inspector should *never* make any adjustments, press any buttons, etc.

Probe and Umbilical Checks

The inspector should check the probe and umbilical for defects, wear, and corrosion. The probe does not have to be taken out of the stack to be inspected. If removing the probe could alter the location or orientation of the probe, it *should not* be removed from the stack. It may be possible to observe the in-stack end of the probe from one of the other stack ports.

System Condition, Configuration, and Maintenance

Defects Wear Corrosion

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Probe

The inspector should look for the following **probe** items during the inspection:

- Verify the probe location as detailed in the monitoring plan and permits for the facility.
- Is the probe in the same location as when it was certified? Same length? Same construction and materials?
- Is the probe securely fastened to the stack or duct?
- Is there evidence the probe has been moved (look at the condition of the bolts holding it in place)? This could be a good or bad point, but should be checked. If the probe has been moved it may have been cleaned, realigned, or replaced--ask and check probe maintenance log records for conditions and calibrations before and after the maintenance.
- What is the condition of the particulate filters? When were they last replaced?
- What is the condition of the probe? Is it clean and in good condition or caked with ash and particulate and corroded?
- Is the calibration gas injected at the probe?

Umbilical

When inspecting the **umbilical** the inspector should check:

- Are there any loops or kinks in the line?
- Is the line corroded, brittle, cut, crushed, or worn at any point?
- Are there any unheated sections? Is the insulation intact?
- Are electrical cables properly routed and protected?
- Are all connections tight and leak free? Do any connections appear to have been recently worked on?

Conditioning and Dilution Air System Checks

The inspector should check the maintenance log for recent repairs and maintenance. The inspector also should check:

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- The connection between the umbilical line and the conditioning system should be tight and leak free.
- Is the drain or condensed water removal system working properly?
- How much contact is there between the stack gas and condensed water?
- Are any fittings corroded or leaking?

Analyzer Checks

The analyzers should appear to be well maintained and operating properly. Generally, they should be rack mounted and connected to the conditioning system with a sample manifold. Tubing and cables should be neatly bundled. Loose and disorganized tubing and cables, while not directly a problem, are an indication of lack of care for the instruments and a sign that the system should be carefully inspected.

The inspector should verify that the analyzers are the same instruments that were previously certified--check the serial numbers and instrument and maintenance logs. If substantial portions of the analyzers have been replaced, either in a significant rebuilding of the instrument or through cumulative parts replacement, the instrument may need to be recertified. The inspector should check:

- Is the system configured as it was when certified?
- Are the cables located near, or bundled with, power lines, electric motors, or equipment that generate strong electromagnetic fields?
- What is the status of the control panel lights, indicators, alarms, etc?
- Note the system flow and pressure readings, are they consistent with the readings during past inspections?
- Is the output from the instrument consistent with the data acquisition and handling system reading?
- How often is the analyzer adjusted? What is the typical magnitude of the adjustments?

Instrument Replacement

Parts Replacement

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Accessories Check

The inspector should be sure to check any and all equipment associated with the system. Most CEM systems have a number of accessories and other equipment that should be checked; some (but not all) of which include:

- Gas cylinders
 - What is the expiration date?
 - What is the cylinder pressure? The cylinder should be replaced if the pressure falls below 100 psi.
 - Is the cylinder gas type and concentration appropriate?
 - Are certification records available?
- Regulators should be the correct type for the gas being handled and not damaged or leaking.
- The condition of plumbing (calibration lines, exhaust lines, etc.) associated with the gas cylinders should be checked for corrosion, leaks, etc.

Data Acquisition and Handling System

The data acquisition and handling system (DAHS) consists of all the hardware, software, and procedures for data recording, retrieving, reporting, and recordkeeping. The DAHS is part of the certified equipment and, as such, the inspector should check that it is the same as when certified. The inspector should ask:

- How does the DAHS work? How does the data transfer from the analyzer to the DAHS? How are other data recorded? If any data are input by hand, check the data against the original hard copy.
- How are quarterly reports generated?
- How missing data substitutions made?
- Ask the source to display the current bias adjustment factor, equations, conversion factors, and calculations.
- How are the daily calibration data recorded. Have the source display the calibration data.

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- How frequently are the data backed-up?

503.7.2 Data and Records Inspections

Review of data and records includes any quality assurance / quality control plans, maintenance and instrument logs, emissions data, and quarterly reports. An inspector should begin this portion of the inspection at the agency office before going to the facility with a review of all files and records. Standardized CEM Summary Report and Data Assessment Report forms are generally used by the source to report CEM data and status. They should be located in the office files and reviewed before the inspection. An example copy of the forms is in Appendix A. In addition, Appendix A contains an Excess Emission Report Review form and a CEM Records Inspection form which an inspector can use for data and records review.

Data, QA/QC Plans, Logs, Reports

Quality Assurance Review

An important part of proper CEM operation is maintaining and following a Quality Assurance Plan (QA). The QA Plan should describe, in detail, complete, step by step procedures and operations for: calibration error tests and linearity checks, calibration and linearity adjustments, preventive maintenance, audit procedures, recordkeeping and reporting, and the specific authority and responsibility for carrying out each activity.

Some important questions for the inspector to ask are:

- How often are the zero and span drift checked? What constitutes excessive drift? Are monitors adjusted when drift is excessive?
- How do they report "out-of-control" conditions in quarterly reports?
- Is a daily calibration check conducted? When? Have them demonstrate.
- What grade cylinder gases are used?

Maintenance Logs Review

The maintenance logs are important documents for determining how well the CEM system has been operating. The logs should contain a spare parts list and a preventive maintenance checklist. They also should document any repair and

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maintenance work done on the instruments. The maintenance logs will point out recurring problems with the CEMs and can direct the inspector toward areas of the system that should be given special attention. The inspector should check:

- Does the preventive maintenance checklist include daily, weekly, and monthly activities?
- Is there a troubleshooting matrix available for the technician to follow if a monitor malfunctions?
- Verify that the spare parts and consumable items (filters, chart paper, etc.) required are readily available, preferably on site.

Emissions Data

During the inspection an inspector should review the monitoring and data records and compare the facility records with values and conditions reported to the agency. Key documents to review are the Excess Emission Report (EER) and the Data Assessment Report (DAR). In addition, the inspector should examine the strip charts and/or computer records for missing, noisy, or flat data; inconsistent data trends; and source operation and emissions annotations. Typically, about 30 CEM operating days of data should be checked, especially those days when there is some indication that the source or CEM operation was erratic.

503.7.3 Audits

A third type of inspection is the audit. This topic is extensively covered in Section 402 of this manual. An audit can be a system audit, an agency oversight audit, or a performance audit. The first two audit types are often conducted by the air pollution control agency personnel, while the third is generally conducted by the source or a contractor hired by the source. The performance audits are scheduled in advance and notification is given to the agency so an observer can be present to inspect the procedure.

**EER
DAR**

**Strip Charts
and Computer
Records**

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504 REFERENCES

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7. U.S. Clean Air Act Amendments, 1990.
8. Air Pollution Training Institute Course 474, Continuous Emission Monitoring Systems, Student Manual, September, 1992.
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10. U.S.EPA, Performance Audit Procedures For Opacity Monitors, EPA/4-92-010, 1992.
11. U.S.EPA, Inspection Guide For Opacity Continuous Emission Monitoring Systems, EPA-340/1-88-002, 1988.
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Calibration Drift (CD) - The difference in the CEM output readings from the established reference calibration value after a stated period of operation during which no unscheduled maintenance, repair, or adjustments took place.

Calibration Error (CE) - The difference between the concentration indicated by the CEMS and the known concentration when the entire CEMS is challenged. A CE test is conducted to document the accuracy and linearity of the CEMS over the entire measurement range.

Calibration Standard - A known amount of pollutant that is presented to the CEMS in order to calibrate the drift or response of the analyzer. The calibration standard may be a gas of known composition and concentration or a filter with a known mass loading or composition.

Centroidal Area - A concentric area that is geometrically similar to the stack or duct cross section and is no greater than 1% of the stack or duct cross sectional area.

Continuous Emission Monitoring System (CEMS) - The total equipment required for the determination of a pollutant concentration.

Cylinder Gas Audit (CGA) - An audit of the CEMS challenging the system with certified calibration gases at two concentration levels.

Data Acquisition and Handling System (DAHS or DAS) - The portion of the CEMS that collects data from the analyzer and performs basic calculations.

Data Recorder - The portion of the CEMS that provides a permanent record of the analyzer output.

Diluent Analyzer - That portion of a CEMS that senses the diluent gas (O_2 or CO_2) and generates an output proportional to the concentration.

Dilution Extractive CEMS - A CEMS that extracts and dilutes an aliquot of flue gas with clean dry air before analysis. The moisture remains in the sample, but is diluted to a point below the dew point and so does not condense in the analysis.

Extractive CEMS - A CEMS that removes an aliquot of flue gas from the stack for analysis.

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In-Situ CEMS - A CEMS that analyzes the flue gas in place in the stack. In-situ CEMS can be either point or path systems.

Out-of-Control Period - The period of time in which the CEMS is incapable of generating valid data as demonstrated by failure of the system to meet the calibration drift specifications.

Path CEMS - A CEMS that measures the pollutant concentrations along a path more than 10% of the equivalent diameter of the stack or duct.

Point CEMS - A CEMS that measures the pollutant concentrations at a single point or along a path less than 10% of the equivalent diameter of the stack or duct.

Pollutant Analyzer - The portion of the CEMS that senses the pollutant concentration and generates a proportional output.

Relative Accuracy - The absolute mean difference between the pollutant concentration determined by the CEMS and the value determined by the reference method (RM) plus the 2.5% error confidence coefficient of a series of tests divided by the mean of the RM tests or the applicable emission limit.

Relative Accuracy Audit (RAA) - An abbreviated RATA test, generally using only three data sets.

Relative Accuracy Test Audit (RATA) - An audit of the CEMS comparing the CEMS output with reference method tests. At least nine data sets are generally required.

Response Time - The time interval between the start of a step change in the system input and the time when the pollutant analyzer output reaches 95% or the final value.

Sample Interface - The portion of the CEMS used for sample acquisition, transport, conditioning, or protection of the analyzer from the effects of the stack effluent.

Span Value - The upper limit of the pollutant concentration measurement range.

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Tolerance Interval - The interval with upper and lower limits within which are constrained a specified percentage of the concentration with a given level of confidence.

Zero Drift - The difference in the CEM output readings from the established reference zero value after a stated period of operation during which no unscheduled maintenance, repair, or adjustments took place.

CONSTANTS

Avogadro's Number	6.02×10^{23} atoms per gram-atom
Faraday constant	9.65×10^4 Coulombs per mole
1 g-mol	22.4 l ideal gas at standard temperature and pressure (STP: 0°C, 1 atm)
1 lb-mol	359 ft ³ ideal gas at STP (32°F, 1 atm)
ln 10	2.3026
Natural log base <i>e</i>	2.7183
Plank's constant	6.62×10^{-27} erg s
Speed of light	3.0×10^{10} cm/s
Speed of sound	344 m/s in air (20°C, 1 atm)
Gas Constant (R)	depends on units of pressure, volume, moles, and temperature used. For example, from the following table, if units of cm ³ , Kelvins, gram moles, and atmospheres are used the value of R is 82.05

Volume	Temp	Moies	Pressure						
			Atm.	psia	mm Hg	cm Hg	in. Hg	in. H2O	ft. H2O
cubic feet	K	gm	0.0029	0.0426	2.2	0.22	0.0867	1.18	0.0982
		lb	1.31	19.31	999	99.9	39.3	535	44.6
	R	gm	0.00161	0.02366	1.22	0.122	0.0482	0.655	0.0546
		lb	0.73	10.73	555	55.5	21.8	297	24.8
cubic cm	K	gm	82.05	1206	62400	6240	2450	33400	2780
		lb	37200	547000	2.83×10^7	2.83×10^6	1.11×10^6	1.51×10^7	1.26×10^6
	R	gm	45.6	670	34600	3460	1360	18500	1550
		lb	20700	304000	1.57×10^7	1.57×10^6	619000	8.41×10^6	701000
liters	K	gm	0.08505	1.206	62.4	6.24	2.45	33.4	2.78
		lb	37.2	547	28300	2830	1113	15140	1262
	R	gm	0.0456	0.67	34.6	3.46	1.36	18.5	1.55
		lb	20.7	304	15700	1570	6.19	8410	701

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COMMON STACK GAS CONSTITUENTS

Molecule	Symbol	Molecular Weight
Oxygen	O ₂	32
Nitrogen	N ₂	28
Water	H ₂ O	18
Carbon Dioxide	CO ₂	44
Carbon Monoxide	CO	28
Sulfur Dioxide	SO ₂	64
Nitric Oxide	NO	30
Nitrogen Dioxide	NO ₂	46
Air (dry @20°C)	—	28.9
Air (saturated @20°C)	—	28.7

STANDARD CONDITIONS

International Scientific Standard Conditions

<u>Pressure</u>	<u>Temperature</u>
760 mm Hg	0°C
101.3 kPa	273 K
29.92 in. Hg	460 R
406.79 in. H ₂ O	
14.696 psia	

EPA Stationary Source Reference Methods

<u>Pressure</u>	<u>Temperature</u>
760 mm Hg	20°C, 293 K
29.92 in. Hg	68°F

EPA Ambient Methods Standard Conditions

<u>Pressure</u>	<u>Temperature</u>
760 mm Hg	25°C
101.3 kPa	298 K
29.92 in. Hg	

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US Gas Industry Standard Conditions

Pressure

30.00 in. Hg

Temperature

60°F

520 R

CONVERSION EXPRESSIONS

Temperature

$K = ^\circ C + 273.15$

Kelvins

$R = ^\circ F + 459.4$

Degrees Rankine

$^{\circ}C = \frac{5}{9}(^{\circ}F - 32)$

$^{\circ}F = \frac{9}{5}^{\circ}C + 32$

Gas Concentration Units

To convert ppm to milligrams per cubic meter (mg/m^3) at a set of standard conditions:

$$\frac{\text{mg}}{\text{dscm}} = \frac{\text{ppm} \times \text{MW}}{22.414 \times (T_{\text{std}} / 273.15)}$$

At EPA standard conditions:

100 ppm CO = 116 mg/m^3

100 ppm HCl = 163 mg/m^3

100 ppm NO₂ = 191 mg/m^3

100 ppm SO₂ = 266 mg/m^3

CONVERSION FACTORS

Energy

1 BTU = 1055 J

1 BTU/hr = 0.293 MW

Density

13.6 in. H₂O = 1 in. Hg

13.6 mm H₂O = 1 mm Hg

Length

1 in. = 2.54 cm

1 ft = 0.305 m

Volume

1 ft³ = 0.0283 m³ = 28.32 liters = 28,320 cm³

1 m³ = 35.31 ft³

1 in³ = 16.4 cm³

Velocity

1 ft/min = 0.508 cm/s

1 ft/s = 30.5 cm/s

Flow Rate

1 m³/s = 2120 ft³/min

1 ft³/min = 28.3 liters/min

1 ft³/hr = 0.47 liters/min

Mass

1 g = 0.0022 lb

1 lb = 453.6 g

Mass Per Unit Volume

1 g/m³ = 0.0283 g/ft³

1 lb/ft³ = 16.02 kg/m³

1 grain/ft³ = 2.29 g/m³

1 mg/m³ = 6.23 x 10⁻⁸ lb/ft³

Pressure

1 atm = 1.01325 x 10⁵ Pa = 14.696 lb/in.²

= 760 torr = 760 mm Hg

= 1040 cm H₂O = 407.2 in. H₂O

Power

1 BTU/hr = 0.2931 W

1 kW = 3413 BTU/hr

Emissions

1 ng/J = 2.326 x 10⁻³ lb/10⁶BTU

1 lb/10⁶BTU = 430 ng/J

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VARIABLES

OD _D	Optical depth or density
l	pathlength
C	Concentration
MW	Molecular weight
B _{ws}	water vapor fraction
T	Temperature
P	Pressure
Δp	Velocity pressure
Q	Flow rate
A _s	Cross sectional area of the stack
v	Velocity
K _p	Pitot tube dimensional constant
C _p	Pitot tube calibration coefficient
c	Speed of sound
I	Light intensity
α	Beer-Lambert Law molecular absorption coefficient
Op	Opacity
i	Current
F	Faraday constant (96500 coulombs)
R	Ideal gas law constant
d	particle diameter
λ	Wavelength of light
E	Emission rate
V	Volume of dry combustion gas
GCV	Gross calorific value of fuel

Subscripts

w	Wet
d	Dry
s	Stack conditions
std	Standard conditions
m	Metered conditions
bar	Barometric
ref	Reference conditions
sample	Sampled conditions

EQUATIONS

Optical Depth (page 200-5)

$$OD = l \times C$$

Conversion of concentration (ppm) to mass emission rate (mg/dscm)
(page 200-7)

$$C = \frac{\text{mg}}{\text{dscm}} = \frac{\text{ppm} \times \text{MW}}{22.414 \times (T_{\text{std}} / 273.15)} \left(\frac{T_{\text{std}}}{T_m} \right) \left(\frac{P_{\text{bar}}}{P_{\text{std}}} \right)$$

Moisture correction (page 200-7)

$$C_w = C_d (1 - B_{ws})$$

Dilution Ratio (page 200-15)

$$R = \frac{Q_1 + Q_2}{Q_2}$$

Pollutant mass emission rate (page 200-29)

$$\text{pmr}_s = C_s Q_s$$

Stack gas flow rate (page 200-29)

$$Q_s = A_s v_s$$

Stack gas velocity by velocity pressure (Δp) (page 200-31)

$$v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{P_s \text{MW}_s}}$$

Stack gas velocity by acoustic velocimetry (page 200-33)

$$v_A = \frac{l}{t_A} = c + v_s \cos \alpha$$

$$v_B = \frac{l}{t_B} = c - v_s \cos \alpha$$

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Stack gas temperature by acoustic velocimetry (page 200-34)

$$T = \left(\frac{c}{K} \right)^2$$

(K = constant)

Beer-Lambert Law (page 200-37)

$$T = \frac{I}{I_0} = e^{-\alpha c l}$$

(T = transmittance)

Pollutant concentration by Beer-Lambert Law (page 200-38)

$$c = \frac{-\ln \left(\frac{I}{I_0} \right)}{\alpha l}$$

Bouger's Law (page 200-40)

$$T = \frac{I}{I_0} = e^{-naQl}$$

(T = transmittance)

Optical transmittance (T) and opacity (page 200-40)

$$T(\%) = 100 - \text{Opacity}(\%)$$

Optical Density (page 200-41)

$$(\text{optical density}) = D = \log_{10} \frac{1}{1 - \text{opacity}} = \log_{10} \frac{1}{T} = \frac{naQl}{2.303}$$

$$D = \frac{A_E c l}{2.303}$$

$$D = \log_{10}(1/T) = -\log_{10}(1 - \text{Op})$$

or

$$\text{Op} = 1.0 - 10^{-D}$$

(T = transmittance, Op = opacity)

Fick's Law of diffusion (page 200-56)

$$i = \frac{nFADc}{d} = kc$$

(n = number of electrons involved, A = area of eletrode, D = diffusion coefficient, d = thickness of diffusion layer,
k = constant)

Electromotive force (page 200-58)

$$\text{emf} = \frac{RT}{4F} \ln \frac{P_{\text{ref}}(\text{O}_2)}{P_{\text{sample}}(\text{O}_2)}$$

Light scattering (page 300-3)

$$\alpha = \frac{\pi d}{\lambda}$$

(α = particle size parameter)

Calibration drift (page 400-9)

$$d_{\text{CD}} = \frac{\text{cylinder gas reference value} - \text{monitor value}}{\text{span value}} \times 100$$

Pollutant concentration, corrected to oxygen (page 400-15)

$$C_s(\text{ppm}_{\text{d,c}}) = C_s(\text{ppm}_{\text{d}}) \frac{20.9 - \text{O}_{2\text{reg}}}{20.9 - \text{O}_{2\text{d}}}$$

Emissions in terms of mass per heat input (page 400-15)

$$E = C_s \times F_d \times \frac{20.9}{20.9 - \text{O}_{2\text{d}}}$$

Dry gas F factor (page 400-15)

$$F_d = \frac{\text{volume of dry combustion gas per kilogram}}{\text{gross calorific value per kilogram}} = \frac{V_t}{\text{GCV}}$$

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Relative accuracy (page 400-18)

$$d_i = RM_i - CEM_i$$

$$S_d = \left[\frac{\sum d_i^2 - \frac{(\sum d_i)^2}{n}}{n-1} \right]^{1/2}$$

$$CC = t_{0.975} \frac{S_d}{\sqrt{n}}$$

$$RA = \frac{|\bar{d}| + |CC|}{RM}$$

Alternative relative accuracy for low emission sources with compliance indicating CEMs (page 400-21)

for pollutant gases:

$$RA_{alt} = \left| \frac{\bar{d}}{AC} \times 100 \right|$$

for diluent gases:

$$RA_{alt} = |\bar{d}|$$

Transmissometer pathlength correction (page 400-26)

$$D_x = (l_x/2l_t)D_t$$

or:

$$Opacity_x = 1 - (1 - Opacity_t)^{l_x/2l_t}$$

Calibration error for transmissometers (page 400-50)

$$CE = |\bar{x}| + |CC|$$

System availability (page 400-52)

$$\text{Availability} = \frac{\text{Total unit operating hours meeting QA criteria}}{\text{Total unit operating hours during the period}} \times 100$$

Error propagation (page 400-58)

$$Er = \sqrt{\sum Er_i^2}$$

Linearity Error (page 400-62)

$$LE = \frac{|R - A|}{R} \times 100$$

Calibration error for gas monitors (page 400-63)

$$CE = \frac{|R - A|}{S} \times 100$$

Bias Adjustment Factor (page 400-65)

$$BAF = 1 + \frac{|\bar{d}|}{CEM}$$

$$CEM_i^{\text{adjusted}} = CEM_i^{\text{monitor}} \times BAF$$